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FTC-TR-72-39

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AD905038

AFFTC

# UH-1N SALT WATER SPRAY INGESTION TESTS (CATEGORY II FOLLOW-ON TEST PROGRAM)


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TECHNICAL REPORT No.72-39

OCTOBER 1972



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DEPARTMENT OF THE AIR FORCE

HEADQUARTERS AERONAUTICAL SYSTEMS DIVISION (AFSC)

WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

11 NOV 1972

REPLY TO ATTN OF: ASD/SDQH 11-27 (Maj Goble/54480/cal/UH-1N)

SUBJECT: ASD Addendum to FTC-TR-72-39, UH-1N Salt Water Spray Ingestion Tests

TO: Recipients of FTC-TR-72-39

This report is a part of and should remain attached to FTC-TR-72-39, "UH-1N Salt Water Spray Ingestion Tests (Category II Follow-on Test Program)". Paragraph numbers below correspond to the recommendations in the AFFTC Technical Report.

1. Concur. Interim Operational Supplement T.O. 1H-1(U)N-1S-40, 6 Jun 72, was issued reflecting this inadequacy.

2. Do not concur. Operational Supplement T.O. 1H-1(U)N-6CF-1S-5, 18 Feb 72, revised FCF topping procedures which are considered adequate.

3. Do not concur. Topping power checks are a maintenance function and should remain in T.O. 1H-1(U)N-6CF.

4. Concur with intent, however, the engine manufacturer considers the present procedures optimum.

5. Concur with intent, the next revision of T.O. 1H-1(U)N-1 will reflect salt water operation.

6. Concur with intent. ECP 533 incorporates an integral wash ring. Frequency of wash is user optional depending on mission.

7. thru 11. Concur. Will be incorporated in the next T.O. 1H-1(U)N-1 revision.

12. Do not concur. Not practical for training, and from a maintenance viewpoint.

FOR THE COMMANDER

William O Eastman Jr

WILLIAM O. EASTMAN, JR., Lt Col, USAF
Chief, Helicopter Program Office
Directorate of Combat Systems
Deputy for Systems

PRIDE IN THE PAST · FAITH IN THE FUTURE

FTC-TR-72-39

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# FOREWORD

The UH-1N salt water spray ingestion tests were conducted from 24 April to 12 May 1972 at the Naval Air Station (NAS), North Island, San Diego, California. The last flight in support of the test effort was conducted at the AFFTC on 23 May 1972. The test engines were removed after completion of the flight test program and sent to the Marine Corps Air Station (MCAS), Cherry Point, North Carolina, for test cell calibration and teardown. This report presents the results of that test program.

Tests were conducted under the authority of AFR 80-14 and Project Directive 72-116, dated 14 March 1972. The test program was requested by the Aeronautical Systems Division, Helicopter Programs Office (ASD/SDQH), in a Program Introduction Document, dated 1 December 1971.

The authors thank the U.S. Navy Commander, Fleet Air San Diego, and personnel of NAS North Island for the cooperation and support provided to the test team during the off-site deployment. The authors also thank Donald Berger, Lieutenant Colonel USAF, for his contribution as a project pilot.

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**25 September 1972**

James W. Wood

**JAMES W. WOOD**
**Colonel, USAF**
**Commander, 6510th Test Wing**

Robert M. White

**ROBERT M. WHITE**
**Brigadier General, USAF**
**Commander**

## ABSTRACT

This report presents the results of the UH-1N salt water spray ingestion test program which was conducted to provide information to the Aerospace Rescue and Recovery Service. The UH-1N was found to lose power at the maximum rate of 1/2 to 1 percent torque per engine per hour of hovering in salt spray. The topping power check was found to be the best inflight indicator of engine power degradation. Topping power check procedures should be included in the Flight Manual to make them available to operational pilots for use in checking engine condition. The presently prescribed performance recovery wash, although too time consuming, was adequate to restore engine power. Spray impingement on the helicopter windscreen was an adequate indication of salt spray ingestion by the engines. Salt spray ingestion occurred at hover heights of 45 feet or less when the aircraft was hovered at gross weights between 9,000 and 10,000 pounds with prevailing winds of 6 to 16 knots. At gross weights of 9,000 pounds or less and wind conditions of 6 to 16 knots, salt spray ingestion occurred at hover heights of 30 feet or less. No ingestion occurred at any hover height down to five feet when wind conditions were five knots or less. Sustained hovering in salt spray caused significant aircraft corrosion problems which required daily corrosion control efforts. Long term corrosion effects may represent a more serious problem than engine power degradation. The improved internal rescue hoist (Engineering Change Proposal 652ERI) operated satisfactorily in the salt spray environment when loaded with 150 pounds of dead weight.

# table of contents

# list of illustrations



**APPENDIX II**

**Right Engine Performance Data**

# list of abbreviations and symbols

| Item | Definition | Units |
|---|---|---|
| ARRS | Aerospace Rescue and Recovery Service | - - - |
| EAPS | engine air particle separator | - - - |
| ITT | inter-turbine temperature | deg C |
| $ITT/\theta$ | referred ITT | deg K |
| MCAS | Marine Corps Air Station | - - - |
| NAS | Naval Air Station | - - - |
| $N_f$ | power turbine speed | rpm |
| $N_g$ | gas generator speed | rpm |
| $N_g/\sqrt{\theta}$ | referred $N_g$ | rpm |
| pph | pounds per hour | - - - |
| SHP | shaft horsepower | 550 ft-lb/sec |
| $SHP/\delta\sqrt{\theta}$ | referred SHP | 550 ft-lb/sec |
| $W_f/\delta\sqrt{\theta}$ | referred fuel flow | pph |

# INTRODUCTION

The UH-1N salt water spray ingestion tests were conducted as a follow-on to the UH-1N Category II test program. Twenty-two flights were conducted at NAS North Island, and a twenty-third took place at the AFFTC on 23 May 1972. The test aircraft was UH-1N helicopter, S/N 68-10774, which had been utilized for the Category II all-weather test program.

The tests were requested by the Aeronautical Systems Division to provide information in support of the Military Airlift Command/Aerospace Rescue and Recovery Service (ARRS). ARRS utilizes the UH-1N to perform overwater operations for the USAF sea survival training and for other missions requiring sustained hover at altitudes low enough to result in operation of the aircraft in salt water spray. Safe operation in this environment required that additional guidance be included in the Flight Manual (reference 1).

To acquire the required information, the test aircraft was hovered in salt spray at hover altitudes from 40 feet down to 5 feet above the surface under varying conditions of relative wind, gross weight, and sea state. In all, 13.7 hours of sustained hovering were accomplished during the conduct of the test.

## TEST OBJECTIVES

The primary test objectives were to determine the following as a result of hovering in a salt water environment:

1. The best inflight indicators of engine power deterioration.

2. The rate of engine power deterioration as a function of gross weight and skid height.

3. The effects of wind conditions and sea state on engine power deterioration.

4. The capability of engine compressor wash procedures to restore lost engine power.

5. The effect of a non-operating engine air particle separator (EAPS) on the rate of engine power deterioration.

The secondary test objectives were to:

1. Qualitatively evaluate the improved internal rescue hoist in the salt spray environment.

2. Identify peculiar maintenance requirements for the hoist or airframe components exposed to salt spray.

## TEST AIRCRAFT DESCRIPTION

The UH-1N helicopter was manufactured by the Bell Helicopter Company, Fort Worth, Texas. It had a single two-bladed lifting rotor and a tractor-type tail rotor instead of the more conventional pusher-type tail

rotor. The UH-1N utilized the basic UH-1D fuselage, but was powered by an engine with twin power sections in contrast to the single power section engine employed by the UH-1D. At the time the salt spray program began, the test aircraft had accumulated 303 airframe hours.

### TEST ENGINE DESCRIPTION

The test aircraft was powered by a United Aircraft of Canada T400-CP-400 engine rated at 1,800 shaft horsepower (SHP). The engine consisted of two independent power sections driving into a combining gearbox. The combining gearbox contained an overrunning clutch and a torquemeter for each power section. For simplification of discussion, the left and right power sections are hereafter referred to as left and right engines.

The left engine, S/N 66007, had accumulated 304 hours prior to this test program. The right engine, S/N 66199, had accumulated 128 hours and the combining gearbox, S/N 4016, 301 hours.

### INSTRUMENTATION

The test aircraft was equipped with a photopanel utilizing calibrated standard aircraft instruments and a 35mm movie camera. Appendix I lists the parameters available on the photopanel. The photopanel instruments received their input from the same signal source as the corresponding instrument in the cockpit, with the exception of the free air temperature probe which was located beneath the pilot station. The photopanel instruments and the cockpit instruments indicated the same parameter value except for differences in specific instrument calibrations.

### DATA REDUCTION

Parameter values extracted from the photopanel film were first corrected for instrument error. The data as corrected to this extent are termed "calibrated" data in this report. Calibrated data were then corrected to standard day sea level conditions (15 degrees C). These data are termed "referred" data in this report.

Corrections necessary to refer the data acquired at NAS North Island to standard day conditions were relatively small since all testing was conducted under conditions of 14 $\pm$3 degrees C ambient temperature, and 50 $\pm$200 feet pressure altitude with the altimeter set at 29.92 inches of mercury.

# TEST AND EVALUATION

The primary area of investigation was engine power deterioration due to sustained hovering in salt water spray. Variables investigated were hover height, aircraft gross weight, relative wind velocity, aircraft heading relative to wind direction, and to the extent possible, sea state. In addition, one flight was flown with the right engine air particle separator inoperative. Table I summarizes the test flights.

Table I

SUMMARY OF FLIGHT TESTS

| Flight No. | Date (1972) | Flight Duration (hrs) | Hover Duration (min) | Hover Height (ft) | Prevailing Winds (kt) | Estimated Wave Height (in.) | Comments |
|---|---|---|---|---|---|---|---|
| 1 | 25 Apr | 0.8 | -- | -- | -------- | -- | Area survey |
| 2 | 25 Apr | 1.0 | 15<br>15 | 40,20,15<br>10 | 14 to 17<br>17 to 19 | 12<br>15 | Hover over seaplane ramp;<br>5 min at each height |
| 3 | 26 Apr | 0.5 | -- | -- | -------- | -- | Left engine ITT limiter out |
| 4 | 27 Apr | 0.4 | -- | -- | -------- | -- | FCF following ITT limiter change |
| 5 | 27 Apr | 1.2 | 30 | 30 | 7 to 12 | 12 | Left engine surging |
| 6 | 27 Apr | 1.0 | 30 | 30 | 7 to 9 | 15 | |
| 7 | 28 Apr | 2.0 | 60 | 20 | 5 to 10 | 15 | |
| 8 | 28 Apr | 1.7 | 60 | 10 | 10 to 16 | 24 | |
| 9 | 1 May | 1.7 | 60 | 10 | 6 to 10 | 12 | |
| 10 | 1 May | 1.0 | 30 | 10 | 10 to 14 | 18 | |
| 11 | 3 May | 2.2 | 70 | 5 | 2 to 5<br>9 to 14 | 12 | 25 hoist cycles |
| 12 | 4 May | 1.7 | 60 | 10 | 9 to 14 | 12 | 24 hoist cycles |
| 13 | 4 May | 1.7 | 60 | 10 | 9 to 14 | 6 | 19 hoist cycles |
| 14 | 5 May | 1.9 | 80 | 15 | 7 to 9<br>9 to 12 | 12 | 24 hoist cycles |
| 15 | 5 May | 1.3 | 45 | 15 | 7 to 10<br>9 to 14 | 12 | 14 hoist cycles |
| 16 | 8 May | 2.0 | 90 | 5 | 7 to 10 | 12 | 20 hoist cycles |
| 17 | 8 May | 1.2<br>---<br>--- | 30<br>--<br>-- | 5<br>40<br>200 | 9 to 12<br>--------<br>-------- | 12<br>--<br>-- | 10 hoist cycles<br>1 hoist cycle<br>1 hoist cycle |
| 18 | 9 May | 1.5 | 30<br>10 | 5 to 50<br>5 to 50 | 7 to 9<br>9 to 12 | 12<br>12 | 10,000-lb gross weight<br>8,000-lb gross weight |
| 19 | 10 May | 1.7 | 45 | 5 | 7 to 10 | 12 | Right engine EAPS inoperative |
| 20 | 11 May | 0.5 | -- | -- | -------- | -- | See Note 1 |
| 21 | 12 May | 0.7 | -- | -- | -------- | -- | See Note 2 |
| 22 | 12 May | 0.7 | -- | -- | -------- | -- | See Note 2 |
| 23 | 23 May | 2.0 | -- | -- | -------- | -- | See Note 3 |

NOTES

[1]Test terminated when initial topping check showed power not regained after engine wash.

[2]Test flown to determine effectiveness of engine wash to restore power.

[3]Test flown at Edwards AFB. Topping power checks performed every 1,000 feet from 3,000 feet PA to 10,000 feet PA increasing.

Inherent in the task of determining the rate of engine power loss experienced was the determination of the best inflight technique of detecting this loss. It is desirable that a pilot be able to detect engine power loss by observing his engine performance instruments while in the hover, or by comparing instrument values during two or more successive inflight power checks. Power assurance checks and topping power checks were evaluated as inflight indicators of engine deterioration to determine which procedure would better provide the pilot with this information.

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| 15 | 5 May | 1.3 | 45 | 15 | 7 to 10<br>9 to 14 | 12 | 14 hoist cycles |
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| 18 | 9 May | 1.5 | 30<br>10 | 5 to 50<br>5 to 50 | 7 to 9<br>9 to 12 | 12<br>12 | 10,000-lb gross weight<br>8,000-lb gross weight |
| 19 | 10 May | 1.7 | 45 | 5 | 7 to 10 | 12 | Right engine EAPS inoperative |
| 20 | 11 May | 0.5 | -- | -- | -------- | -- | See Note 1 |
| 21 | 12 May | 0.7 | -- | -- | -------- | -- | See Note 2 |
| 22 | 12 May | 0.7 | -- | -- | -------- | -- | See Note 2 |
| 23 | 23 May | 2.0 | -- | -- | -------- | -- | See Note 3 |

NOTES

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Inherent in the task of determining the rate of engine power loss experienced was the determination of the best inflight technique of detecting this loss. It is desirable that a pilot be able to detect engine power loss by observing his engine performance instruments while in the hover, or by comparing instrument values during two or more successive inflight power checks. Power assurance checks and topping power checks were evaluated as inflight indicators of engine deterioration to determine which procedure would better provide the pilot with this information.

## TEST PROCEDURE

The test aircraft was hovered in salt water spray for progressively longer times until a full two hours of hovering was accomplished at a particular test height. Accumulation of two hours hovering required two flights at the same hover height in the same day. For safety reasons, the left engine was washed between the two flights. The right engine was not washed, and so accumulated the full two hours exposure.

Hover heights from 40 feet down to 5 feet were investigated; however, the test effort was concentrated at hover heights of 15, 10, and 5 feet. A full two hours of hovering was achieved at each of these three hover heights. Accurate altitude information was provided during the hover by a radar altimeter.

## DETECTION OF POWER LOSS WHILE HOVERING

An attempt was made to detect power degradation as it occurred in the hover. As the initial hover was established, torque, gas generator speed ($N_g$) and inter-turbine temperature (ITT) were noted. These parameters were observed as the hover progressed to determine if changes in these parameters could be correlated to power degradation.

Several factors worked against the pilot in his attempt to hold a constant hover height and constant power setting. While hovering at 15 feet or less, winds in the range of 6 to 16 knots, whether constant or variable, combined with ground effect to cause a constantly changing hover height. Any attempt to set a constant power with the collective and allow the helicopter to follow the sea swells produced an out of phase vertical oscillation of two to three feet. Maintaining a constant hover height under these conditions required variations of $\pm 3$ to 4 percent torque and changes of $\pm 5$ degrees C ITT. The continually required directional pedal inputs to maintain constant heading also caused power variations. All of this resulted in constantly fluctuating instrument indications which made detection of any small changes caused by ingestion of salt spray impossible.

Another factor which further reduced chances of detecting power loss in the hover was the build-up of salt deposits on the main and tail rotor blades, which reduced their aerodynamic efficiency. For example, at the beginning of testing on one day, a power-required-to-hover check showed 68 percent indicated torque required. The aircraft was hovered in the spray for one hour during which a particularly heavy build-up on the rotor blades was experienced. The aircraft was refueled for the second flight of the day, but not washed. A power-required-to-hover check at the beginning of the second flight showed an increase to 72 percent indicated power required. The two checks were performed at approximately the same gross weight and under approximately the same test conditions. The four percent increase in power required was due to decreased aerodynamic efficiency of the blades caused by the heavy salt deposits.

These factors made it difficult to give definitive guidance on detecting power loss in the hover. Only increases in ITT of over 5 to 10 degrees C for a given torque setting gave any indications of engine deterioration due to salt incrustation.

For prolonged hover operations, torque requirements should decrease as fuel burnoff reduces aircraft gross weight. Consequently, a constant or increasing torque would indicate probable loss of rotor blade efficiency. Either this condition or compressor blade incrustation would cause a corresponding increase in indicated ITT. In order to determine the true increase in ITT, the original hover torque must be set by retarding the throttle on one engine momentarily. This same procedure would be required even if there had been a decrease in torque requirements, and it was desired to know the true extent of any ITT decrease. Setting a specific torque under the unstable conditions of hovering in ground effect and over water was difficult. If this procedure were successfully used to show an increase in ITT had occurred during the hover, a topping power check would still be required to determine if the engine had deteriorated below minimum power requirements.

Observation of the cockpit performance instruments while maintaining a hover in salt spray was not sufficient by itself to indicate engine power deterioration resulting from engine ingestion of salt spray.

## POWER ASSURANCE CHECKS

Power assurance checks were performed on the ground prior to and after each hovering flight throughout the test program. Initially, power assurance checks were also performed in conjunction with inflight topping power checks in an attempt to correlate the two checks. Beginning with flight 12, inflight power assurance checks were not performed.

Figure 1 presents a time history of the performance parameter, ITT, for both engines during power assurance checks. Data from flights 1 through 4 have been omitted for both engines because these flights were of short duration and were troubled with a malfunctioning left engine ITT limiter.

It was also noted that the right engine consistently operated approximately 25 degrees C hotter than the left engine, and after flight 19 this difference increased to approximately 45 degrees C. Higher operating temperatures on the right engine were noted on all test aircraft during the Category II performance testing (reference 2).

Power assurance checks performed on both engines on the ground generally produced 10 to 20 degrees higher indicated ITT than those performed in flight. This made it impossible to compare the initial ground check with any of the subsequent inflight power assurance checks. A comparison was possible, however, between the pre-hover and the post-hover ground power assurance checks and between successive inflight checks.

Inflight power assurance checks did not correlate with the inflight topping power checks. During flight 7, the left engine lost approximately 1 percent torque during successive topping checks while the ITT decreased approximately 7 degrees C during power assurance checks. During flight 9, the left engine ITT increased 5 degrees C while topping checks showed almost a 2 percent loss in topping power torque. Flight 11 was flown almost entirely in wind conditions insufficient to cause salt water spray impingement on the helicopter. During this flight the left engine showed no torque degradation, but the ITT increased 10 degrees C during successive power assurance checks.

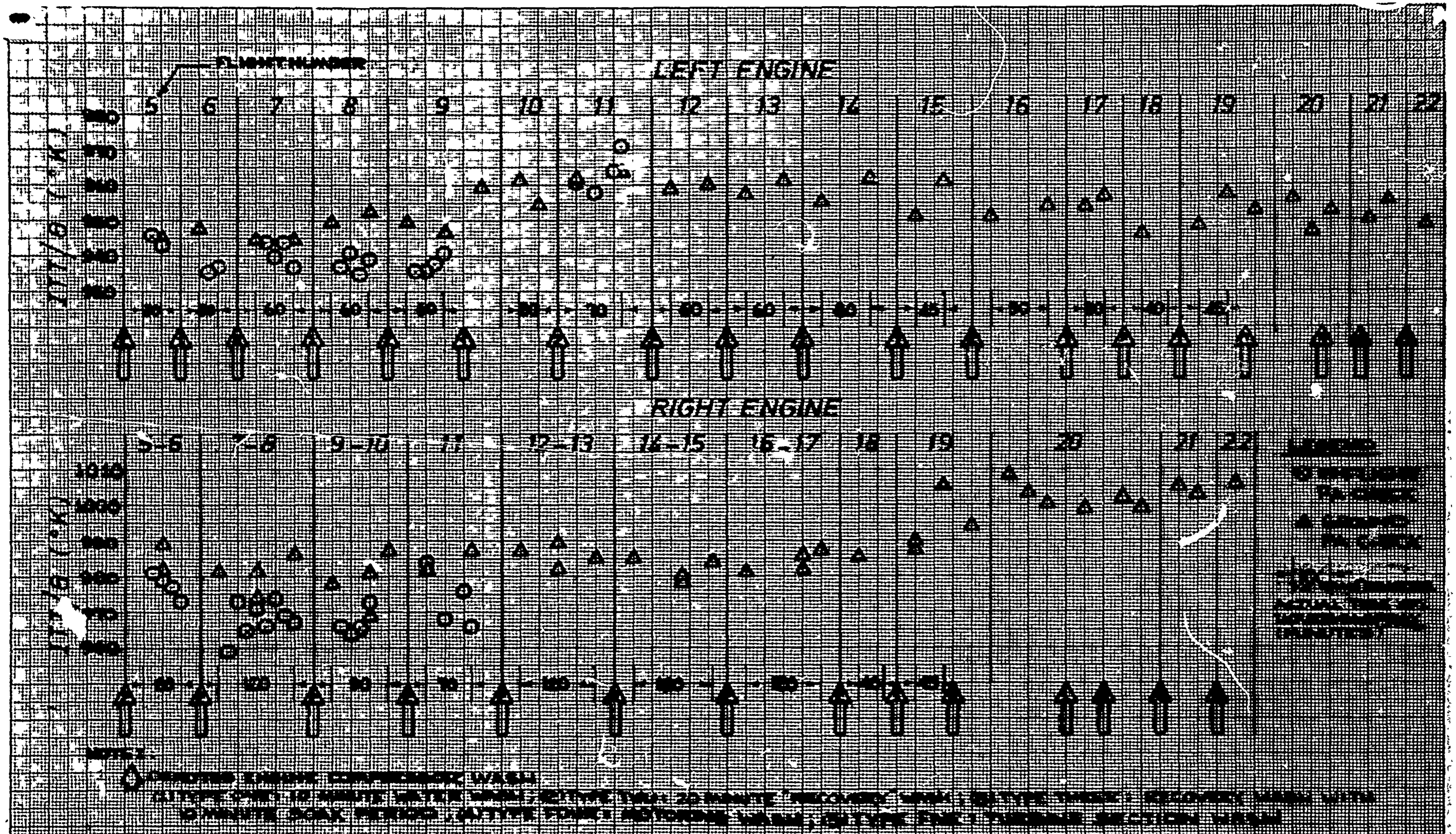



FIGURE 1: TIME HISTORY OF REFERRED INTER-TURBINE TEMPERATURE RECORDED DURING POWER ASSURANCE CHECKS

A similar lack of correlation existed on the right engine. During flights 7 and 8, the right engine exhibited no power loss for the first 1 1/4 hours, then showed a decrease in torque of almost one percent after 1 1/2 hours and almost 2 percent after 1 3/4 hours. The inflight power assurance checks did not reflect the same marked change in ITT during the second hour of the hover, but showed an increasing/decreasing variation within a 10-degree C band for almost the entire flight and a consistent decreasing trend during the last 30 minutes of the hover. During flight 11, the right engine also showed no loss of topping torque; however, the right engine ITT decreased almost 20 degrees C during power assurance checks.

For these reasons, the practice of performing inflight power assurance checks was abandoned. Power assurance checks performed on the ground appear to be more reliable. Figure 1 shows the post-hover power assurance check generally yielded a higher value of ITT than the pre-hover check. The increase is, however, generally small, being on the order of 5 to 10 degrees C.

During flight 19, both engines lost approximately 2 percent torque during 45 minutes of hovering. Both engines also exhibited a relatively large increase in power assurance ITT. The right engine showed an increase of 15 degrees C. Following flight 19, power could not be regained on the right engine by washing it, and the power assurance checks performed after flight 19 substantiate this in that ITT was not reduced on subsequent power assurance checks.

Although there may be some merit in attempting to gauge engine condition by power assurance checks, obviously a check performed on the ground does not satisfy the requirements of determining power degradation in flight. Further, a relatively small increase in ITT of 5 to 10 degrees C corresponded to power losses on the order of 2 percent torque. The power assurance check was therefore not sensitive enough to detect small (1/2 to 1 percent torque) power losses.

Successive power assurance checks were not adequate indicators of engine power degradation resulting from the ingestion of salt spray. Power assurance checks should not be used as a basis for engine rejection due to power deterioration below minimum acceptable values. **(R 1)**[1]

## TOPPING POWER CHECKS

Topping power checks were performed in level forward flight prior to the beginning of hovering in salt spray and after completion of each 15-minute increment of hovering during a test sortie. The procedure used was to increase collective with one engine at idle until the other engine reached an indicated $N_g$ limit of 100 percent or an indicated 810 degrees C ITT. Power turbine rpm ($N_f$) was kept constant at 97 percent by "drooping" or "beeping" the rotor rpm. After it was demonstrated that power degradation was not occurring rapidly enough to warrant checking every 15 minutes, the interval between checks was lengthened to 30 minutes. The 30-minute interval was used beginning with flight 10.

[1] Boldface numerals preceded by an R correspond to the recommendation numbers tabulated in the Conclusions and Recommendations section of this report.

Initially, topping power checks were recorded following a 30-second stabilization period, as required by the current Functional Check Flight Procedures (reference 3). The 30-second wait was found to be satisfactory if the engine was topped on $N_g$. If the engine was topped on ITT, however, a stabilization period of four to five minutes was found to be required to determine maximum available power because the temperature decreased slightly after several minutes of holding topping power. This permitted an increase in collective until the indicated ITT was restored to 810 degrees C. The increase in collective resulted in an increase in torque of approximately one percent.

During the test program, the left engine generally topped on $N_g$ while the right engine generally topped on ITT. This difference was reported in reference 2.

The present wording in the Functional Check Flight Procedures is inadequate in that it does not make a distinction between the stabilization period required when topping on $N_g$ and topping on ITT. Reference 3 should be amended to include instructions to hold topping power four to five minutes if necessary to obtain stabilized engine performance when topped on ITT. **(R 2)**

The topping power check was the best method evaluated of determining inflight engine power degradation and is the basis of the following section on deterioration rates. Topping power check procedures were included in the Functional Check Flight Procedures, but not in the Flight Manual. So that all operational pilots may utilize the topping check to determine engine power degradation, topping power check procedures should be included in the Flight Manual. **(R 3)**

Topping power checks may be performed in a hover, in level forward flight, or in a climb. There is sufficient latitude as to where to perform the topping check, but there are some operational disadvantages. Topping power checks must be done carefully to yield correct torque readings. A tenth of a percent low $N_g$ or a few degrees ITT below 810 degrees C was found to yield an erroneously low torque value.

Topping power checks are also considered too time consuming, particularly if the engine being checked tops on ITT. In this case, obtaining the maximum value of indicated torque requires holding topping power four to five minutes for engine stabilization, as previously discussed. A UH-1N operationally hovering in salt spray could require two topping checks per engine per mission. One topping check would be required to determine initial acceptability and a possible second check would be required to determine acceptability after some predetermined duration of hovering in the spray. Assuming both engines topped on ITT, a minimum of 20 minutes could be expended just for checking engines. In consideration of the limited fuel endurance of the UH-1N, this reduction in useful mission time could be operationally unsatisfactory.

One possible alternative might be to develop an $N_g$/ITT relationship in which a constant value of $N_g$ (95 percent for example) could be set and the indicated value of ITT used as the basis for engine acceptance. Successive checks by this procedure would give an indication of progressive power loss. Development of an $N_g$/ITT relationship was a specific recommendation made in reference 4.

If this type procedure were used it would also result in less error in reading the instruments because the $N_g$ gauge can be read with greater accuracy than the torque indicator. An easier and more efficient method of determining engine performance during flight should be developed for the T400 engine. (R 4)

## POWER DETERIORATION RATE

The right engine was subject to more severe power deterioration because it was allowed to accumulate the hover time accomplished during two flights in a given day. The left engine was washed after every flight with either a 10-minute water wash or a 10-minute Turco solution wash followed by a 10-minute water wash.

Topping power checks performed on both engines were used as the basis for a determination of engine degradation with time in the hover. In the relatively narrow range of 65 to 70 percent torque the instrument error was nearly constant, so that a decrease in calibrated torque of 1 percent was equivalent to a 1 percent decrease in indicated torque. Unfortunately, topping power checks introduced an element of scatter in the data. It was therefore necessary to consider all the topping power checks in a given flight to determine the power loss for that flight. A point by point analysis was not practical.

Figure 2 presents a time history of calibrated torque and its derivative, referred shaft horsepower, ($SHP/\delta\sqrt{\theta}$), for all topping power checks performed on the left engine at NAS North Island. Figure 3 presents the corresponding values of referred gas generator speed ($N_g/\sqrt{\theta}$) and referred inter-turbine temperature ($ITT/\theta$). Data from flights 1 through 6 have been omitted because of the short duration of these flights and because of severe fluctuations experienced as a result of a malfunctioning ITT limiter.

Figures 4 and 5 present the time history of these parameters for topping power checks performed on the right engine. Data from flights 1 through 4 have been omitted due to the short duration of those flights. Table II summarizes the hover time and power degradation experienced by each engine during each flight. For purposes of analysis, an engine compressor was assumed to have been cleaned by an engine wash and, therefore, returned to a "zero hover time" condition after each engine wash.

The more frequent wash given the left engine is reflected in the fact that no power deterioration was experienced during flights 8, 11, 12, 15, 16, and 17. The right engine experienced no power loss only during flight 11 which was flown almost entirely in wind conditions too light to cause spray impingement on the test aircraft.

The left engine experienced a 2 percent torque loss after 1 hour during flight 13 and a similar loss after only 45 minutes during flight 19. A 1.4 percent loss was noted during the 80-minute flight 14. Torque losses of approximately 1 percent were experienced during the 60 minutes of flight 7 and 45 minutes of flight 9. Torque losses of 0.6 percent and 0.5 percent were experienced during flights 10 and 18, respectively.

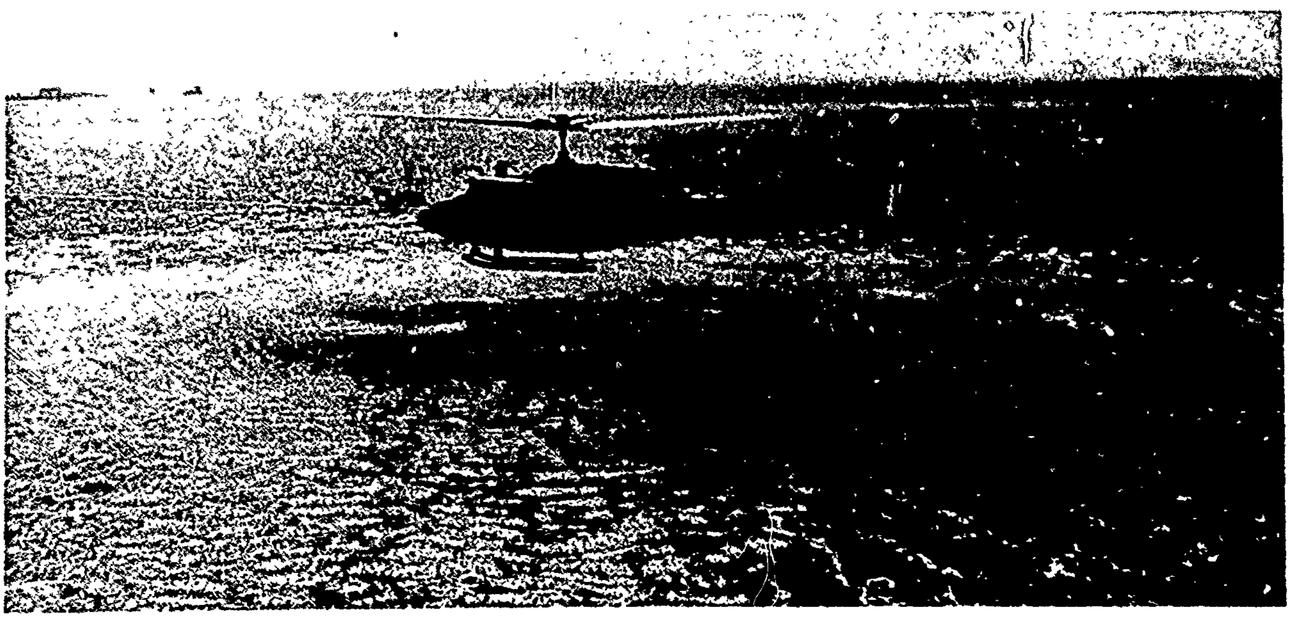
The right engine lost approximately 2 percent of its torque after 2 hours of hovering during flights 7 and 8, 12 and 13, and 16 and 17.

Only 0.9 percent was lost during a 2-hour hover at 15 feet during flights 14 and 15. A torque loss of approximately 1 percent was experienced after 1 hour during flights 5 and 6 and flights 9 and 10. A similar 1 percent loss was noted by the pilot during flight 18 which was inadvertently not recorded on the photopanel. During flight 19, a 2 percent torque loss was experienced after only 45 minutes.

Generally, little, if any, power loss occurred during the first 30 minutes of a given flight. This was probably because a power loss was not observable until the salt incrustation reached an extent sufficient to change the aerodynamic contour of the compressor blades. This apparently did not occur until after the 30-minute point, assuming an initially clean compressor.

The maximum power loss observed after two hours of hovering was two percent torque. With the exceptions of the left engine power loss during flight 13 and the power loss of both engines during flight 19, the maximum power loss after 60 minutes was 1 percent torque. It is concluded that engine power loss as a result of sustained hovering in salt spray occurs at the rate of 1/2 to 1 percent torque per hour of hovering. Since two hours of hovering is beyond the fuel endurance limit of a UH-1N, an aircraft with two percent excess torque demonstrated during its initial pre-hover topping check should be able to perform its mission without power degradation to below minimum acceptable values.

An aircraft which has less than two percent excess torque could experience power degradation to below acceptable values during its mission. In this case, topping power checks are required after predetermined lengths of sustained hovering in salt water spray. Prior to initiation of hovering in salt water spray, a topping power check should be performed to determine initial acceptability. If an engine demonstrates two percent excess power or more, its condition need not be checked during the salt water mission. If the engine shows less than 2 percent excess power, a topping power check should be performed after each 30 minutes of hovering in the salt spray. **(R 5)**



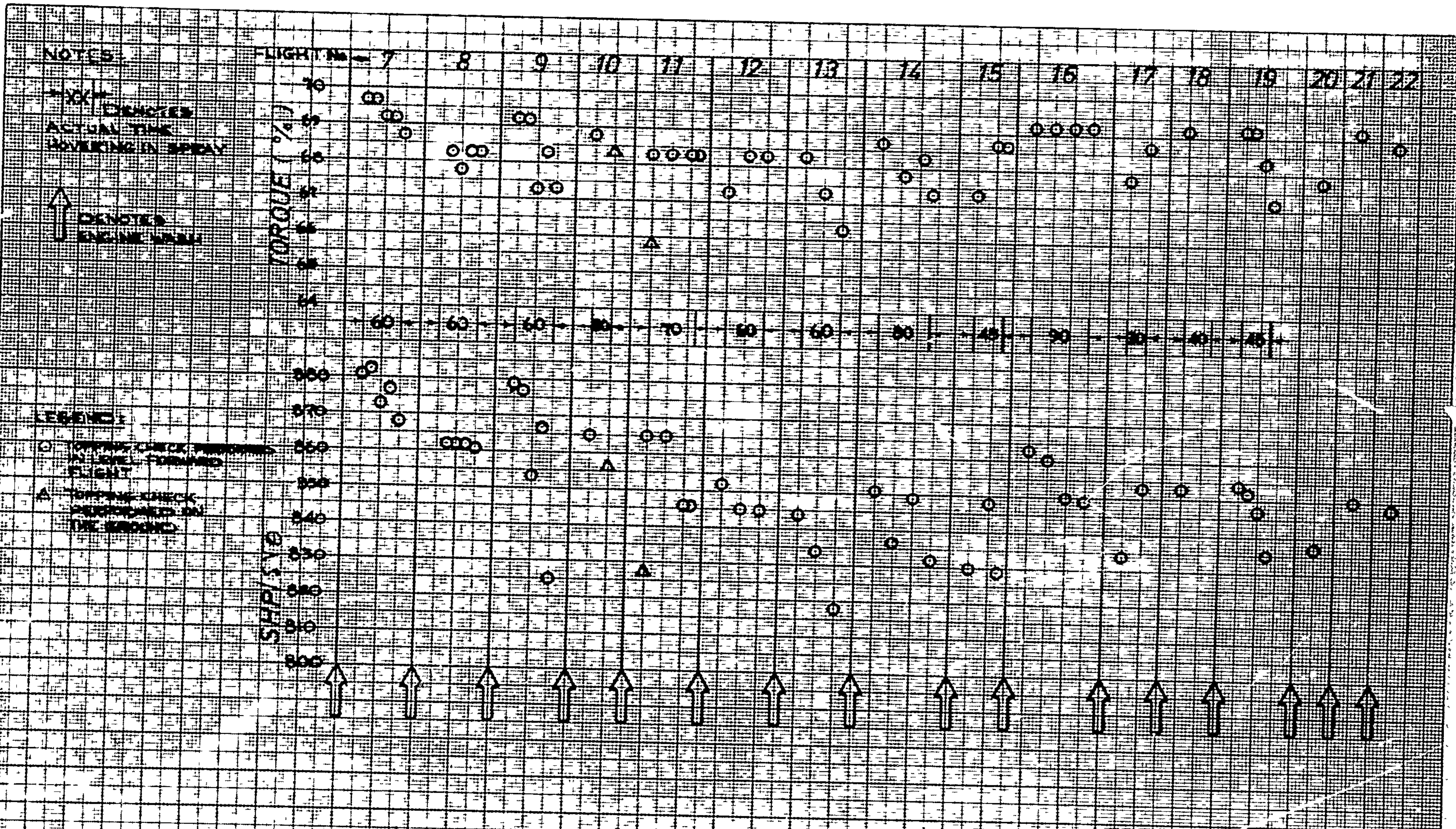



FIGURE 2: TIME HISTORY OF CALIBRATED TORQUE AND REFERRED SHAFT HORSEPOWER FOR LEFT ENGINE TOPPING POWER CHECKS

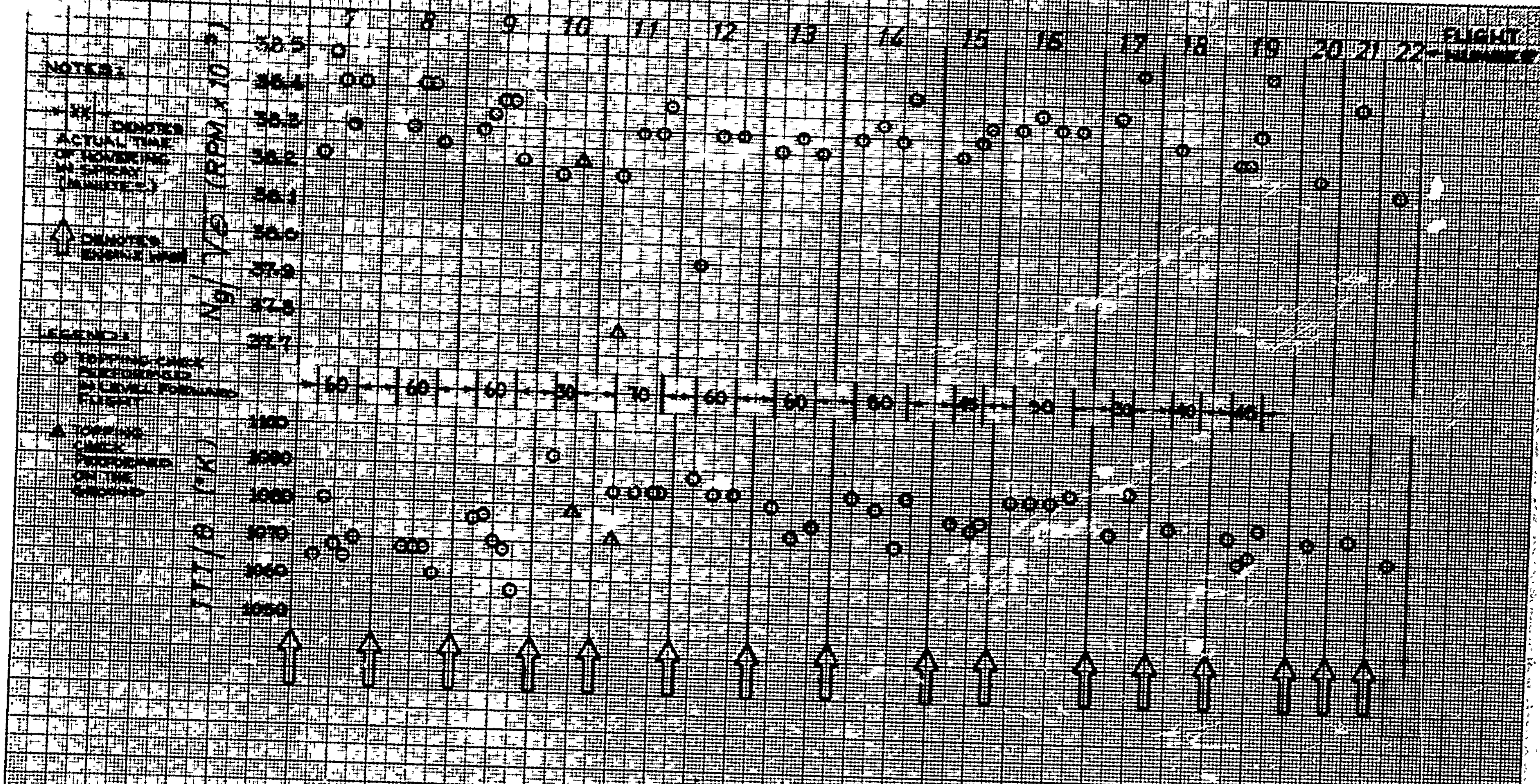



FIGURE 3: TIME HISTORY OF REFERRED GAS GENERATOR SPEED AND REFERRED INTER-TURBINE TEMPERATURE FOR LEFT ENGINE TOPPING POWER CHECKS

Table II

POWER DETERIORATION

| Left Engine | | | | Right Engine | | | |
|---|---|---|---|---|---|---|---|
| Flight No. | Hover Height (ft) | Hover Time (min) | Power Loss (pct torque) | Flight No. | Hover Height (ft) | Hover Time (min) | Power Loss (pct torque) |
| 5 | 30 | 30 | ---- | 5&6 | 30 | 60 | 0.9 |
| 6 | 30 | 30 | ---- | 7&8 | 20&10 | 120 | 1.9 |
| 7 | 20 | 60 | 1.0 | 9&10 | 10 | 90 | 1.0[c] |
| 8 | 10 | 60 | None | 11 | 5 | 70 | None |
| 9 | 10 | 60 | 0.9[a] | 12&13 | 10 | 120 | 1.9 |
| 10 | 10 | 30 | 0.6 | 14&15 | 15 | 125 | 0.9 |
| 11 | 5 | 70 | None | 16&17 | 5 | 120 | 2.0 |
| 12 | 10 | 60 | None | 18 | 5to50 | 40 | 1.0[b] |
| 13 | 10 | 60 | 2.0 | 19 | 5 | 45 | 1.9 |
| 14 | 15 | 80 | 1.4 | | | | |
| 15 | 15 | 45 | None | | | | |
| 16 | 5 | 90 | None | | | | |
| 17 | 5 | 30 | None | | | | |
| 18 | 40 | 5-50 | 0.5[b] | | | | |
| 19 | 45 | 5 | 2.0 | | | | |

[a]After 45 minutes; engine not topped at 60-minute check.

[b]Cockpit indicated values used, photopanel data not acquired.

[c]After 60 minutes; 90-minute check (ground) not topped.

## ENGINE WASH PROCEDURES

The test aircraft was equipped with a permanent wash ring assembly (ECP533 R/C) which provided an even distribution of wash solution into the front of the engine compressor. The wash ring assembly was designed to interface directly with the engine wash cart.

The new engine wash cart which had been specifically designed for the UH-1N aircraft was not available. An existing General Electric engine wash cart was modified so that its output pressure (and consequently flow rate) could be regulated. The system was calibrated to allow setting the flow rate at 0.33 to 0.50 gallons per minute as required by the T400 engine. The modified wash cart was functionally adequate, but it was capable of washing only one engine at a time.

After each day of flying in which hovering in the salt spray was accomplished, both engines were given a performance recovery wash in accordance with Operational Supplement T.O. 1H-1(U)N-2-2S-3. The performance recovery wash consisted of a 10-minute wash with a solution of 1 part Turco to 20 parts demineralized water. Following this, a 10-minute demineralized water only wash and a 1-minute drying out period (engine operation above 80 percent $N_g$) completed the performance recovery wash.

On any day in which two hovering flights were accomplished, the left engine was given a 10-minute demineralized water wash between the two flights. The left engine was washed because it consistently produced less indicated topping power torque than did the right engine. This apparent right engine superiority was later virtually eliminated by application of corrections for instrument error.

Engine washes are denoted in figure 1 by a vertical arrow with a numeral in the arrow head. The numeral designates the type of engine wash given. On figures 2 through 5, only the vertical arrow is shown.

The 10-minute water wash (type 1) was not as successful in cleaning the engine compressor as was the performance recovery wash (type 2). The left engine lost 2 percent topping power torque during flight 13 which was preceded by a 10-minute water wash. It is probable that the salt build-up accumulated during flight 12 was not removed. The water wash following flight 7 was also a failure, and that following flight 16 was only partially successful.

The performance recovery wash following each day's flying was generally successful, although some were more successful than others. The left engine showed substantial recovery after flight 13 when given a Turco-water wash. Full recovery back to 69 percent calibrated torque was achieved following a performance recovery wash performed at the completion of flights 8, 15 and 17.

The right engine showed substantial or full recovery after flights 6, 8, 12, and 13. The wash following flight 15 was only partially succesfull, and that following flight 10 was unsuccessful.

No conclusion can be drawn with regard to the specific effect of Turco in the performance recovery wash, since the comparison was between a 10-minute wash cycle and a 20-minute wash cycle. The possibility remains that a 20-minute water wash might be as effective as the 20-minute performance recovery wash when performance loss is due to compressor blade salt incrustation.

After completion of the test program, the test engines and combining gearbox were removed and sent to the Naval Air Rework factory, MCAS Cherry Point, for priority teardown. Upon disassembly, no salt deposits were found on the axial compressor blades or stators, centrifugal compressor rotor or diffuser, or anywhere in the internal gas path of the power sections. The teardown results substantiated the test results through flight 17, namely that the presently authorized performance recovery wash was adequate to remove salt deposits from the T400 compressors.

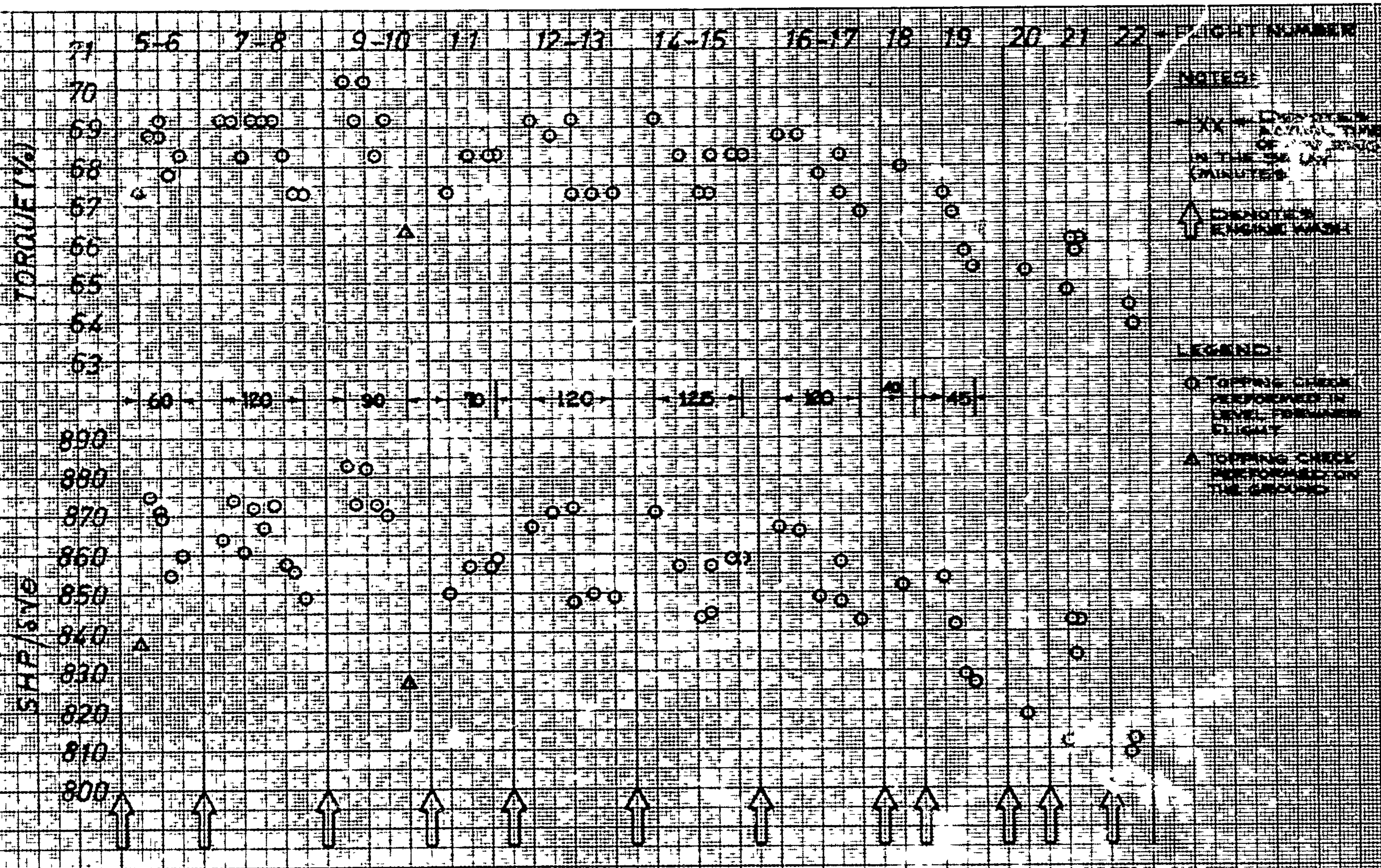



FIGURE 4: TIME HISTORY OF CALIBRATED TORQUE AND REFERRED SHAFT HORSEPOWER FOR RIGHT ENGINE TOPPING POWER CHECKS

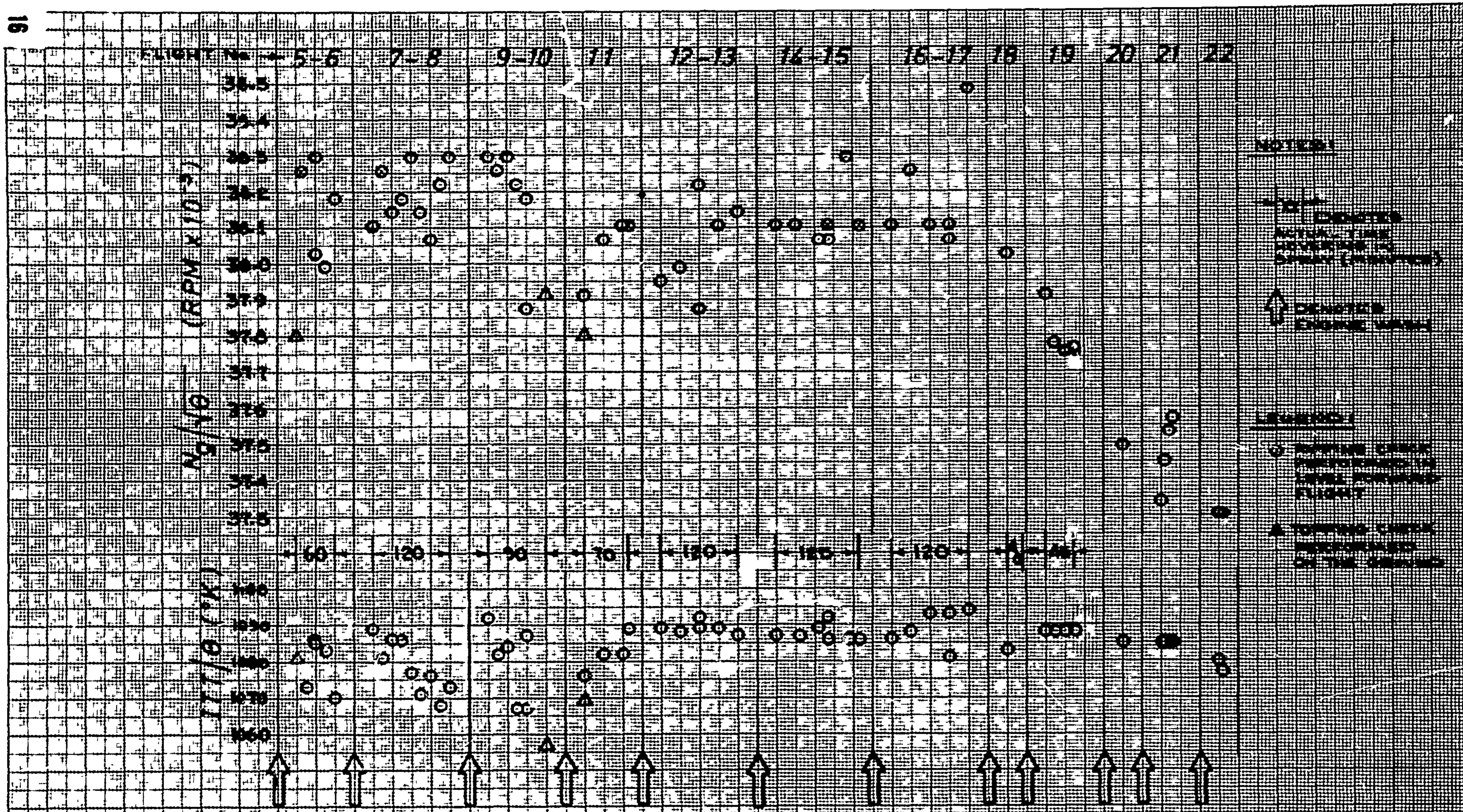



FIGURE 5: TIME HISTORY OF REFERRED GAS GENERATOR SPEED AND REFERRED INTER-TURBINE TEMPERATURE FOR RIGHT ENGINE TOPPING POWER CHECKS

## VARIATION IN ENGINE WASH PROCEDURES

Following flight 18, both engines were given a 10-minute water wash in lieu of the normal performance recovery wash. This was done because the supply of Turco was nearly exhausted and because the performance loss during the flight was small.

On the following day, flight 19 was accomplished with the right engine particle separator door closed rendering the right engine EAPS inoperative. During this flight, both the left and right engines lost approximately two percent topping torque, and both engines were given a full performance recovery wash after the flight.

The initial topping check performed during flight 20 showed no significant improvement in power available from either engine as a result of the performance recovery wash following flight 19. Since both engines exhibited marginal topping torque, the planned mission (a repeat of flight 19 with EAPS inoperative) was cancelled. It was suspected that the engines had not been effectively cleaned of salt deposits and an effort was therefore undertaken to wash them clean. The right engine was given a 10-minute water wash. A power assurance check performed following this wash showed no significant decrease in ITT from the value observed following the completion of flight 19 (figure 1).

The right engine cowlings were removed and the first stage compressor blades and stators were examined to the limited extent possible. The blades appeared clean except for some discoloration where the wash ring discharge had impacted the blades. The cowlings were re-installed, and another performance recovery wash was performed on both engines. A 10-minute soaking period was allowed between the Turco solution wash and the water wash. This wash procedure is designated as type 3 on figure 1. Postwash power assurance checks showed no improvement as a result of this engine wash.

On the following morning, 12 May, another engine wash procedure was utilized. It was theorized that the specified wash procedure of washing the engine while it was running, did not permit wash solution to reach the rear of the compressor, combustor or turbine sections.

A decision was made to perform an engine wash while the engine was motored, rather than while it was running. Water was run through the wash ring assembly while the engines were motored through a normal 30 second starter duty cycle. The engines were then allowed to soak for 1-1/2 hours before the engines were started. This procedure is designated as wash type 4 on figure 1.

Flight 21 was then accomplished with the object of determining through inflight topping power checks whether or not lost engine power had been restored. It was demonstrated that the left engine was restored to a full 69 percent calibrated torque. The right engine showed a very slight improvement after topping power was held a full five minutes or longer. A total of four topping checks were performed on the right engine and although slightly improved, engine power continued to be marginally acceptable.

An attempt was then made to wash out the power turbine section of both engines. After the engines had cooled, water was hosed into the

exhaust end of the engines and allowed to soak. This procedure is designated as wash type 5 on figure 1.

Flight 22 was then accomplished as a repeat of flight 21. Topping power checks showed that this last wash procedure was not successful in restoring right engine power and, in fact, the right engine showed a further decline in power available. It was concluded that the right engine could not be restored by washing it. The right engine did not exhibit enough excess power available to permit any further hovering in salt spray.

The results of the motoring engine wash were inconclusive. While the left engine apparently was restored to full power after this wash, the test was not performed under controlled conditions and was not repeated.

Presently the published procedure specifies a 10-minute running engine wash if the engine has been exposed to salt air. A shorter motoring engine wash is specified as an alternative to this procedure. A performance recovery wash is specified if the engine shows definite signs of deterioration. There is no provision however, for a shorter motoring performance recovery wash as an alternate procedure.

A full performance recovery wash would require 25 minutes if both engines were washed simultaneously and 45 to 50 minutes if the engines were washed consecutively. This running wash requires a pilot to be at the aircraft controls for the entire period of the wash. This procedure would be very time consuming for an operational unit which would require one and possibly two performance washes per day per aircraft. Although the presently specified performance recovery wash was satisfactory for cleaning the engines, shorter wash cycles which might achieve the same results while requiring less ground running should be investigated. **(R 6)**

**ENGINE AIR PARTICLE SEPARATOR INOPERATIVE**

Flight 19 was flown with the right engine air particle separator door closed. It was anticipated that the right engine would deteriorate faster than the left engine because the right engine would ingest spray particles of sufficient mass to otherwise bypass the engine through the open separator door. During the flight, both the left and right engines lost approximately two percent topping torque. This represented the most rapid power loss experienced on either engine during the entire test program.

A possible explanation lies in the fact that following flight 18, the engines were given a 10-minute water wash instead of a 20-minute recovery wash. The possibility exists that the engines were not thoroughly cleaned by this abbreviated wash and therefore began flight 19 with sufficient salt residue on the compressor blades and stators to cause a rapid power loss.

As discussed previously, the left engine was restored to full power by washing it while the right engine could not be restored. Since the right engine did not have enough power margin to permit further hovering in salt spray, the EAPS-inoperative flight could not be repeated. The test aircraft was returned to Edwards AFB for investigation of the apparent power loss. No conclusions can be drawn with regard to the effect of an inoperative EAPS on the rate of engine power degradation resulting from sustained hover in salt spray.

## RIGHT ENGINE POWER LOSS INVESTIGATION

Immediately upon return to Edwards AFB, a series of topping power checks were performed on the ground. When the aircraft first returned, the right engine produced approximately 5-1/2 percent less indicated torque than the left engine. On subsequent checks the right engine produced progressively less torque until the engine produced 9-1/2 percent less indicated torque than the left engine. Maintenance personnel found the right engine had a malfunctioning compressor bleed valve which remained open past the 95 percent $N_g$ scheduled closure point. The bleed valve was changed and a subsequent ground topping check showed the right engine to be improved, but still producing 4-1/2 percent less indicated topping torque than the left engine.

The removed bleed valve was found to be worn and scored where the valve was sticking in the valve sleeve. No evidence of salt water corrosion or other evidence of detrimental effects of hovering in the salt spray were found on the bleed valve. Figure 6 illustrates the scoring on the disassembled bleed valve.

Figure 6 Disassembled Right Engine Compressor Bleed Valve

The malfunctioning bleed valve is felt to have been responsible for the continued decline of the right engine after the test team returned to Edwards. It is not believed to have been totally responsible for the loss of power during flight 19 and subsequent flights through 22. This is evidenced by the behavior of the engine after the bleed valve was changed.

The engine and engine components were functionally checked with no other discrepancies found. The engine ITT limiter, ITT bias, torque indicating system and thermocouple harness were checked according to the applicable Technical Order procedures and were found to be within limits. A voltage check of the aircraft ITT indicating system was performed without the engine running and the system was found to be within limits.

In order to obtain additional data, a twenty-third flight was accomplished on 23 May at Edwards AFB. This flight was made after the bleed valve change and was intended to provide topping power checks at altitude. Topping power checks were made at 1,000-foot increments from 3,000 to 10,000 feet PA. The right engine failed to meet minimum required topping power at 5,000 feet PA and above. The engine produced the minimum acceptable power at 3,000 and 4,000 feet PA. The left engine exceeded power requirements on all eight topping checks.

The topping checks performed at altitude showed the right engine to be performing essentially as it did during flights 19 to 22 at NAS North Island. Appendix II (figures 12-16) presents the performance data for the right engine during topping power checks. The data are segregated between flights 5 to 18, 19 to 22, and 23.

The engine data show a downward shift during flight 19 which continues through flight 23. The performance plot of referred ITT versus referred fuel flow ($W_f/\delta\sqrt{\theta}$) shows a marked shift to the left, meaning less fuel was required to reach 810 degrees C indicated ITT. This, in turn, would most likely indicate a malfunction of the ITT indicating systems.

## TEST CELL CALIBRATION AND TEARDOWN

The engines and gearbox were removed and sent to MCAS Cherry Point for test cell calibration and teardown. This work was accomplished between 1 and 3 August 1972. The difficulty experienced with the right engine could not be duplicated at MCAS Cherry Point, and the right engine actually exhibited slightly better performance than the left engine.

Both engines were torn down for internal visual inspection. The combining gearbox was not disassembled. No evidence of internal corrosion or other harmful effects of salt spray ingestion were found in either engine. No discrepancy capable of causing the apparent right engine power loss experienced during flight 19 was found. Unfortunately, the right engine ITT limiter box used during the test program was not received with the engine at MCAS Cherry Point. The ITT limiter could not therefore be eliminated as the source of the difficulty. As stated earlier, however, the ITT limiter had been checked on the installed engine prior to the decision to remove the engine and was found to be within limits.

The internal condition of the engines as revealed by the teardown demonstrated that sustained hovering in salt spray is not detrimental to the internal components of the T400 engine. The difficulties experi-

enced with the right engine during flights 19 to 23 could not be specifically identified as to cause and whether or not they were induced by hover in salt spray or occurred coincidentally with the test program. The difficulties are attributed to a nonrepeatable electrical malfunction of the engine or aircraft ITT systems.

## ROTOR BLADE SALT INCRUSTATION

Relatively heavy salt incrustation on the tail rotor and main rotor blades was first noted after completion of flight 8. This flight was the second flight of the day and marked the first time in the test program that two hours of hovering in salt spray had been accomplished in a single day.

The salt incrustation appeared in places as a rough lacquer-like deposit which was too hard to be scraped with a fingernail, but which could be scraped with a pen knife. In other locations on the blades, the incrustation appeared as whitish streaks extending from the leading to the trailing edge of the blades. All salt deposits were easily removed when the aircraft was washed with a water hose. Figures 7 and 8 illustrate the salt deposits on the tail rotor and main rotor blades, respectively.

On several subsequent flights, increases in aircraft vibration were noted as the aircraft was hovered toward the end of a one-hour sortie. The vibrations were initially felt in the tail rotor as a "buzz" when the pedals were moved. After translation into forward flight, the main rotor was out of track by two to three inches. The out-of-track condition was attributed to asymmetrical salt build-up on the main rotor blade tabs. This condition was not experienced on every flight, but once encountered, could be felt at airspeeds as low as 50 to 60 knots and remained until the salt build-up was washed off. Figure 9 illustrates the asymmetrical salt build-up on the rotor tab.

No attempt was made to determine the effects of blade incrustation on the performance and flying qualities of the test aircraft. It appears reasonable, however, that the buildup of salt on the blade surfaces would reduce blade efficiency, and the out-of-track condition, once encountered, could reduce the cruise speed of the aircraft. Tail rotor vibrations, while annoying to the pilot, did not appear to restrict the operational capability of the helicopter.

The Flight Manual should be amended to include the following statement: (R 7)

> Sustained hovering in salt spray will cause salt incrustation on the main rotor and tail rotor blades. Such salt incrustation may cause abnormal aircraft vibrations which may be felt as a one per revolution "beat" from an out-of-track main rotor blade, tail rotor pedal "buzz" or higher frequency airframe vibrations transmitted from the tail rotor.

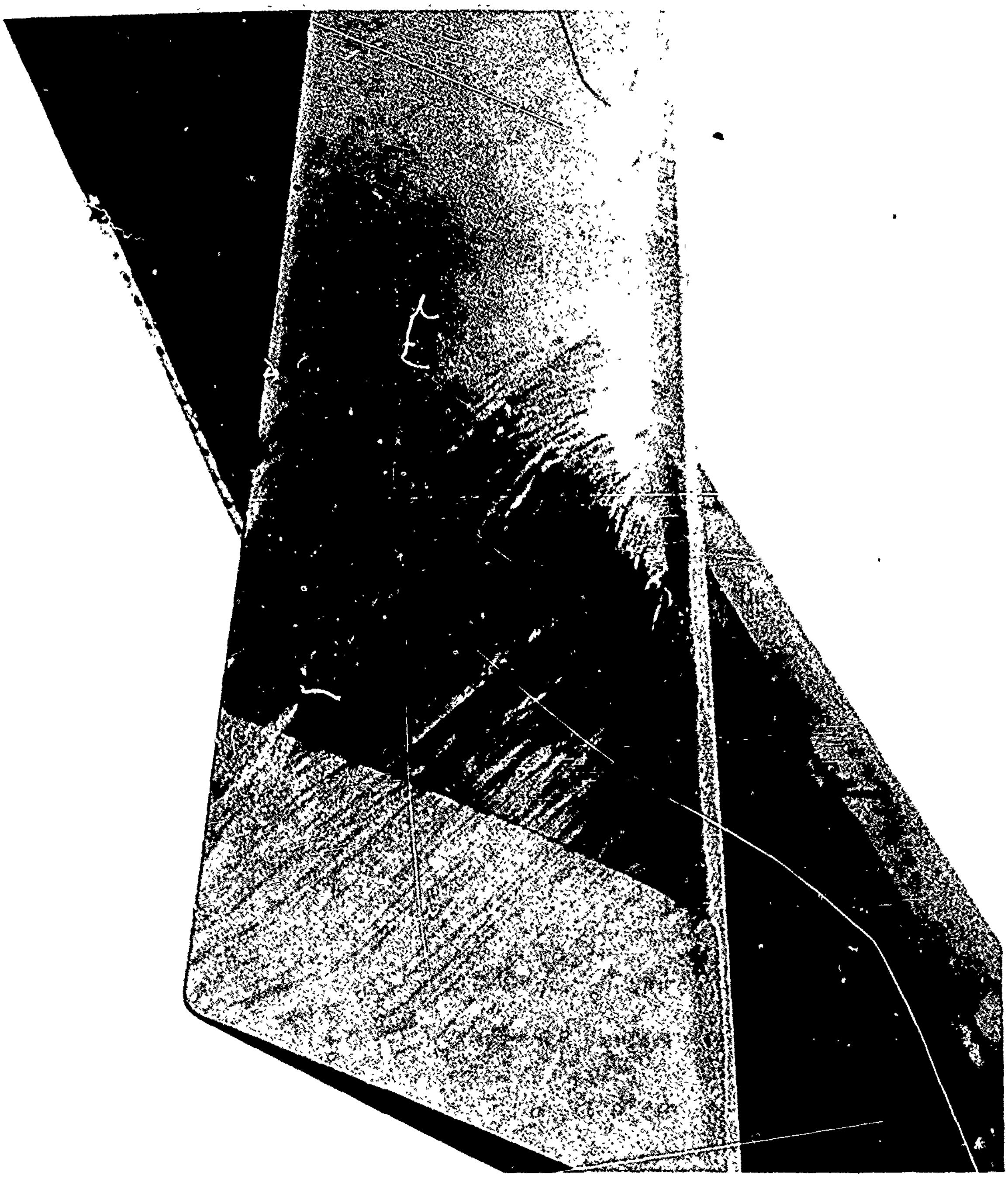


Figure 7 Salt Deposits on Tail Rotor

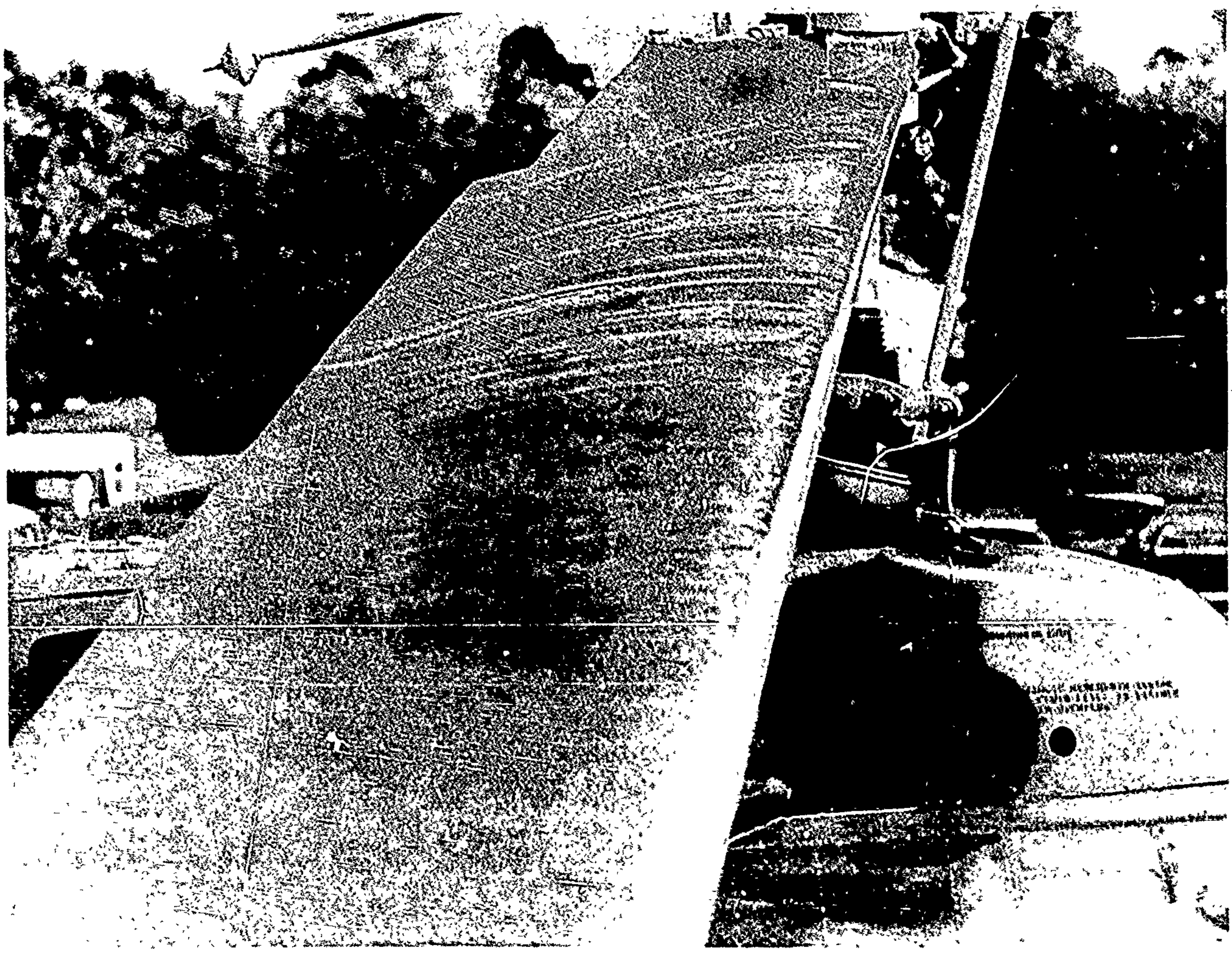


Figure 8 Salt Deposits on Main Rotor

Figure 9 Asymmetrical Salt Build-Up on the Main Rotor Tab

## SPRAY PATTERNS

The baseline determination of spray patterns was made by hovering the aircraft into the wind at an approximate takeoff gross weight of 9,000 pounds. This procedure was used on all test flights where the primary objective of the flight was a determination of engine power loss at a predetermined hover height.

It was determined that spray impingement on the helicopter primarily resulted from salt spray particles being carried aloft by the rotor downwash and then being blown back onto the helicopter by the prevailing winds. The hovering helicopter was observed from a rescue boat and from the beach (through binoculars). These observations confirmed that spray impingement on the windshield coincided with spray ingestion by the engine intakes. Since the flight crew cannot see the engine intakes, spray impingement on the windscreen was found to be the best indication of salt spray ingestion by the engines.

When hovering into the wind, the salt spray tended to blow across the airframe at an angle from right to left. This was probably a result of the counter-clockwise rotation of the main rotor blades. Salt streaks on the airframe generally ran across the airframe at approximately a 30-degree angle from right to left.

Because of the right to left predominence of the spray and because of the location of the engine intakes close to and behind the rotor mast, the right engine intake was more critically located in terms of exposed frontal area. The left engine intake was partially shielded by the rotor mast fairing. In terms of rate of power deterioration experienced during sustained hovering in the salt spray, the right engine may deteriorate at a slightly faster rate than the left engine, assuming that both engines start out with equally clean compressors.

### Effects of Wind Conditions on Spray Patterns

The test aircraft was not instrumented to measure spray intensity. Spray intensity was therefore evaluated qualitatively by observing the impingement rate on the windshield. A correlation between spray intensity, hover height and prevailing wind velocity was made by periodically clearing the windshield with the windshield wipers and observing the spray impingement rate. At no time was the spray intensity high enough to require continuous use of the windshield wipers to maintain adequate visual reference.

It was determined that wind velocities of six knots or greater were required to blow salt spray back onto the windshield and hence into the engine intakes. The test aircraft was hovered as low as five feet skid height above the water without encountering windshield impingement when the prevailing wind was five knots or less.

As wind velocity increased above 6 knots a very light spray impingement was noted at 25 feet hover height. The impingement threshold remained at 25 to 30 feet for wind velocities up to 16 knots. It appeared that wind velocities at the higher end of the 6 to 16 knots range blew the spray particles behind the aircraft before they could be carried to hover heights higher than 25 to 30 feet by the recirculating downwash.

No prevailing winds higher than 16 knots were encountered during the test program.

Once the aircraft was established in the salt spray, decreasing hover altitude caused the spray intensity to increase. As a generality, spray intensity was characterized as very light at 25 feet, light at 15 feet, and moderate at 5 feet. As stated, continuous use of the windshield wipers was not required, even at five feet hover height.

Wind gusts momentarily increased or decreased the intensity of the spray impingement, depending on the hover height of the aircraft and the velocity of the gust. With prevailing winds of five knots or less, the UH-1N could be hovered down to five feet hover height without ingestion of salt spray and accompanying power loss. With prevailing winds of 6 to 16 knots and aircraft gross weight at 9,000 pounds or less, salt spray ingestion and accompanying power loss occurred at hover heights up to 25 to 30 feet.

#### Effect of Gross Weight on Spray patterns

For flight 18 the test aircraft was loaded for a takeoff gross weight of 10,000 pounds. The aircraft was then flown at hover heights from 50 feet to 5 feet to qualitatively evaluate changes in spray patterns from those experienced at 9,000 pounds gross weight. The prevailing winds for the flight were 7 to 9 knots. No marked change in the intensity of the spray was noted. The threshold of spray impingement was raised to 40 to 45 feet, however. The increased downwash velocities associated with the increased gross weight were sufficient to raise the spray particles an additional 15 feet from that experienced at 9,000 pounds (25 to 30 feet). At takeoff gross weights near 10,000 pounds, salt spray ingestion occurred at hover heights of 40 feet or less.

The test aircraft then resumed the hover without refueling to determine the effects of decreased gross weight on spray patterns. The aircraft gross weight was reduced to approximately 8,000 pounds. The prevailing winds had increased to 9 to 12 knots by the time that the flight was resumed at the lighter gross weight. No significant change in spray intensity or spray pattern was experienced from that previously demonstrated at 9,000 pounds gross weight. The spray threshold was encountered at approximately 25 feet.

#### Effects of Sea State on Spray Patterns

The test program was conducted over sheltered water so that hovering over large swells was not accomplished. The majority of the test program was conducted over waves of one foot or less. There did not appear to be any increase in spray intensity or spray patterns when two-foot swells were encountered, particularly if they came in regular intervals with wide spacing between. A slight increase in spray intensity was noted when the water was choppy. Hovering over choppy water, the rotor downwash had a tendency to cut off the tops of the wavelets, thereby increasing the total quantity of airborne spray.

### DOWNWIND AND CROSSWIND HOVERING

Crosswind and downwind hovering were evaluated at a hover height of five feet with prevailing winds of seven to nine knots. Both right and

left crosswind hovering were evaluated. It was found that crosswind hovering substantially increased the pilot workload, particularly when trying to maintain directional control. Spray impingement on the helicopter during crosswind hovering was heaviest on the upwind side.

Downwind hovering increased the pilot workload above an acceptable level for prolonged hovering operations. Spray intensity was increased during downwind hovering because the tail rotor recirculated more of the spray onto the airframe. The results demonstrated that there is no advantage in hovering crosswind or downwind for overwater hover operations due to the increased pilot workload. All overwater hover operations should be conducted into the wind when there is sufficient wind to cause spray impingement on the helicopter windshield (winds of six knots or greater). (R 8)

## HOVER ALTITUDES

The test aircraft was hovered at skid heights from out-of-ground effect (40 feet) down to 5 feet to determine the effects of hover altitude on salt spray patterns.

While accumulating the required hover time at each of the test hover heights, the pilot workload was qualitatively evaluated. Hovering over water is difficult in any case due to a lack of adequate visual reference. An anchored boat was used as a reference during the test program. Operationally, an aid of this type may not be available.

The difficulty of hovering over salt water at low altitudes is increased by gusty wind conditions, poor directional stability in hover, and instability of the helicopter due to downwash recirculation when hovering in ground effect.

In wind conditions of 6 knots or greater, the hover workload proved very high at skid heights of 10 feet or less, and prolonged hovering at these skid heights was very tiring. Both project pilots agreed that 15 feet was a good compromise between a relatively stable hover height and a hover height from which adequate visual reference could be maintained. While this hover height did not keep the helicopter out of the spray pattern, it did reduce the intensity of the spray from that encountered at 10 feet or less. For prolonged hover operations over water, hover altitudes below 15 feet should not be used unless required by operational necessity. (R 9)

## AIRCRAFT CORROSION

Corrosion control required continuous maintenance attention during the entire period that the test aircraft was deployed to NAS North Island. As required by the test plan, the helicopter was thoroughly washed with fresh water after each day of flying in which hovering in salt spray was accomplished.

Visible signs of corrosion began to appear by the beginning of the second week of the deployment. The aircraft had accumulated three and one half hours of hovering in the salt spray and had been thoroughly washed four times during the first week of deployment.

Navy maintenance personnel at North Island were particularly helpful in providing corrosion control advice, silicone spray lubricant and "Zip Aerosol Corrosion Shield." This preservative conforms to MIL SPEC C-16173, grade 4 and was used to both spot treat corrosion (after cleaning the affected area) and to prevent corrosion from occuring in prime suspect areas.

Zip Aerosol Corrosion Shield reduced the total corrosion which did occur on the aircraft, but it was not totally effective in preventing corrosion. Appendix III presents a corrosion summary by aircraft section of the corrosion events which occurred at NAS North Island. Figure 10 illustrates the corrosion formed on the mast spline shaft at the damper mounts.

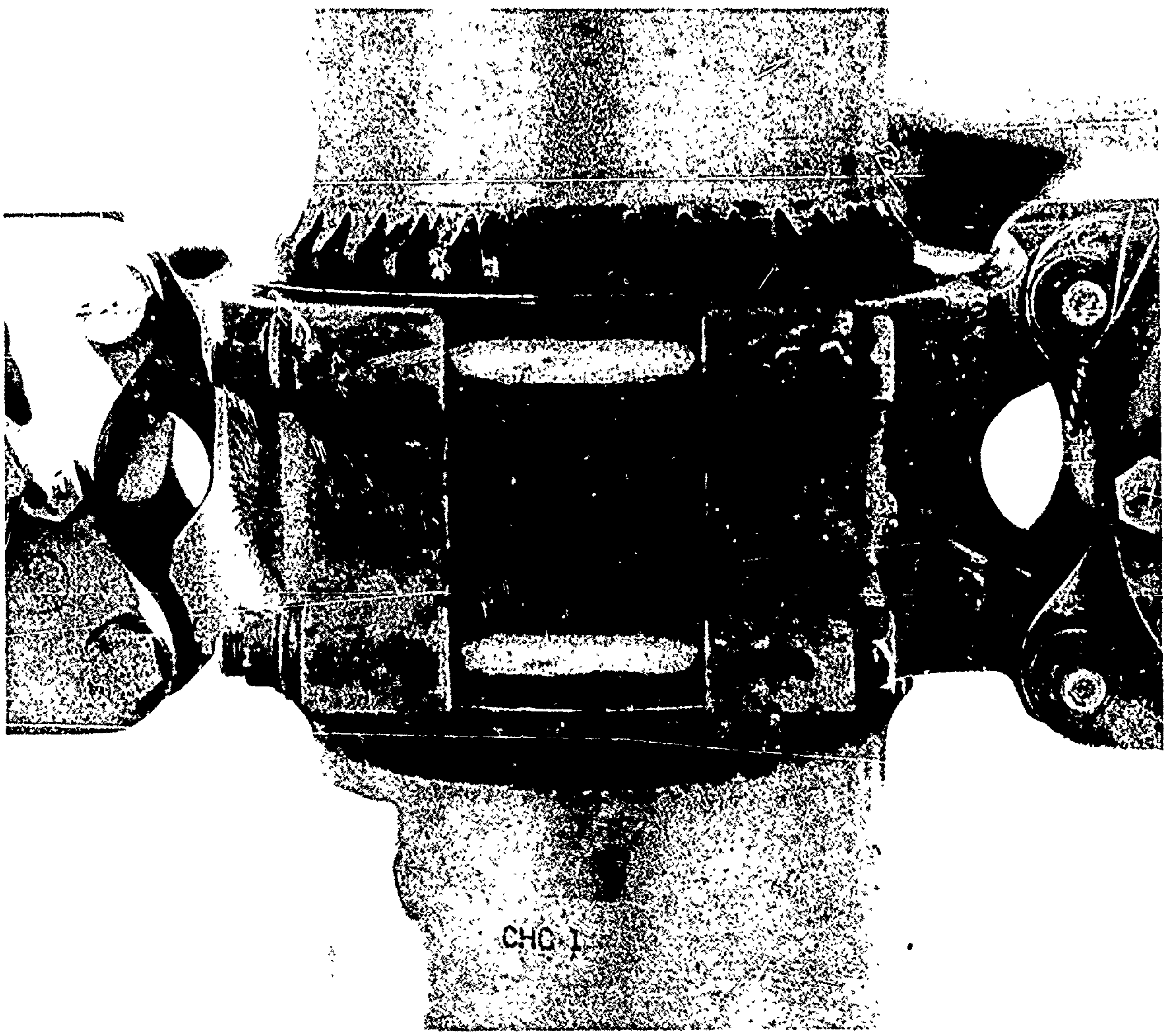



**Figure 10 Corrosion of the Mast Spline Shaft at Damper Mounts**

Upon return to Edwards AFB, The test aircraft was again put through corrosion control procedures. Spot treating and repainting were required in numerous locations on the airframe.

In addition, the left engine starter generator was found to be corroded and to have armature difficulties which required that it be removed and replaced. Sporadic periods where the generator did not carry its share of the load were experienced during the last week of the deployment. During checks at Edwards, the starter-generator failed. Figure 11 illustrates one area of corrosion found on the generator after its removal.

The exact condition of the generator prior to initiation of the test program is not known. It cannot be positively concluded, therefore, that the corrosion found on the generator was caused by hovering in salt spray. However, the possibility that this was the case is strong enough that it cannot be ignored.

It can be positively concluded that hovering in salt spray will cause extensive aircraft corrosion unless adequate corrosion control is practiced on a daily basis. This corrosion may be obvious or insidious and may prove to be a more serious problem than engine power degradation resulting from sustained hovering in salt spray. Hovering in salt spray should be kept to the minimum time required to accomplish an operational mission and hover altitude should be as high as is practical for that mission. (R 10)

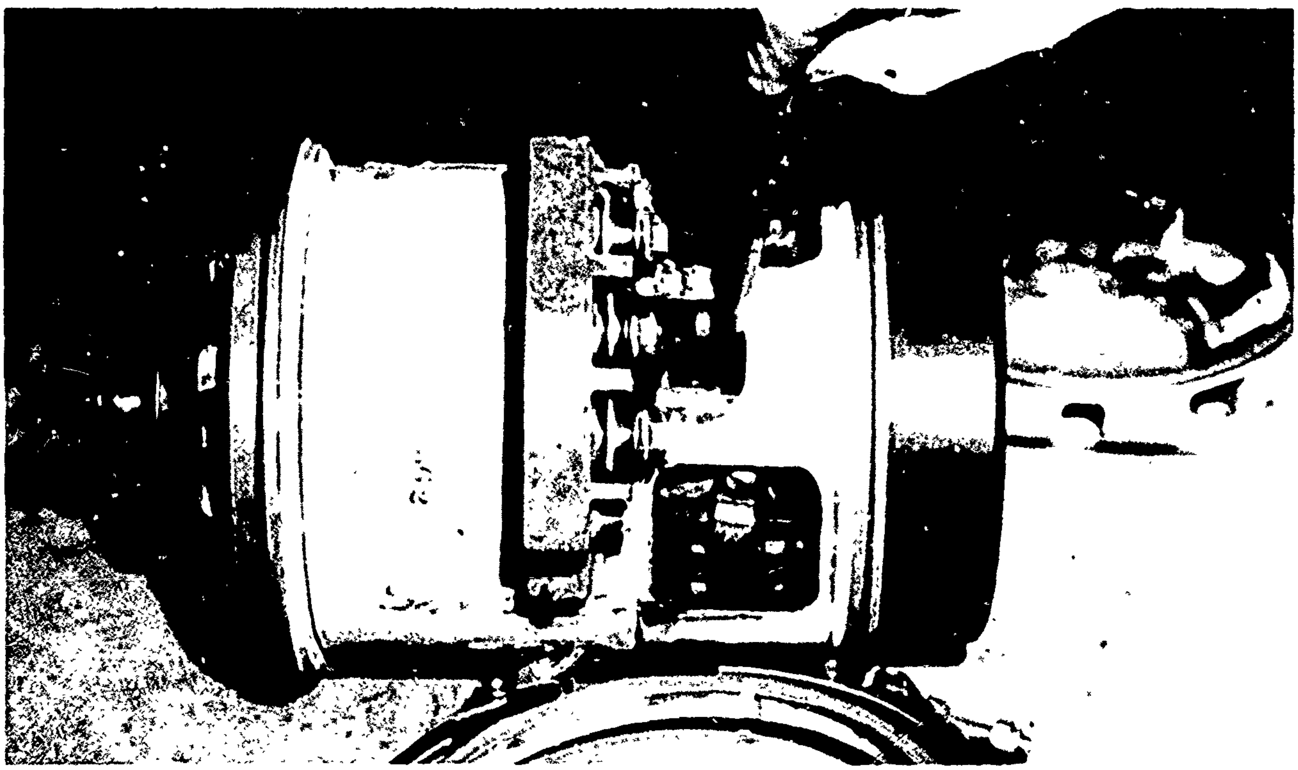


**Figure 11 Corrosion of Left Engine Starter-Generator**

## EMERGENCY EXITS

There was considerable interest generated in the safety aspects of this test program. One of the safety precautions exercised during the conduct of the test was frequent functional checking of the pilots' jettisonable doors. Although not specifically included in the test objectives, there is sufficient interest in this subject to warrant inclusion of the results of those functional checks in this report.

During the test program the left and right pilot's doors were jettisoned approximately eight times each. This was accomplished primarily to insure that the doors would function properly if it was necessary to jettison the doors in an emergency situation. It was also accomplished to determine if the jettison mechanism and the door hinges were corroding and to insure pilot familiarity with the system.

A number of "techniques" were used by the pilots to separate the door from the aircraft after the emergency handle was pulled. These were a manual push against the bottom of the door as stated in Section III of the Flight Manual; kicking the door sharply at the bottom forward corner; and pushing with the shoulder at shoulder height.

The method which consistently resulted in a quick clean separation of the door was the sharp kick at the bottom forward corner. This method could be easily accomplished even from the left seat with the collective control in any position. Pushing by hand, foot or shoulder normally required a second effort and the separation was not as quick and clean as when the kick method was used.

It would seem prudent for all pilots engaged in frequent overwater operations with the UH-1N to be thoroughly familiar with jettisoning the pilot's doors. The doors are easily re-installed and actual jettison would provide both pilot familiarization and functional checking of the system. The UH-1N Flight Manual should be amended to include a NOTE advising of the necessity to use the kick method of door jettison instead of the present "manual push" method. Pilots operating the UH-1N overwater should be required to periodically practice jettisoning both the left and right pilot's doors. **(R 11)** , **(R 12)**

## IMPROVED INTERNAL RESCUE HOIST

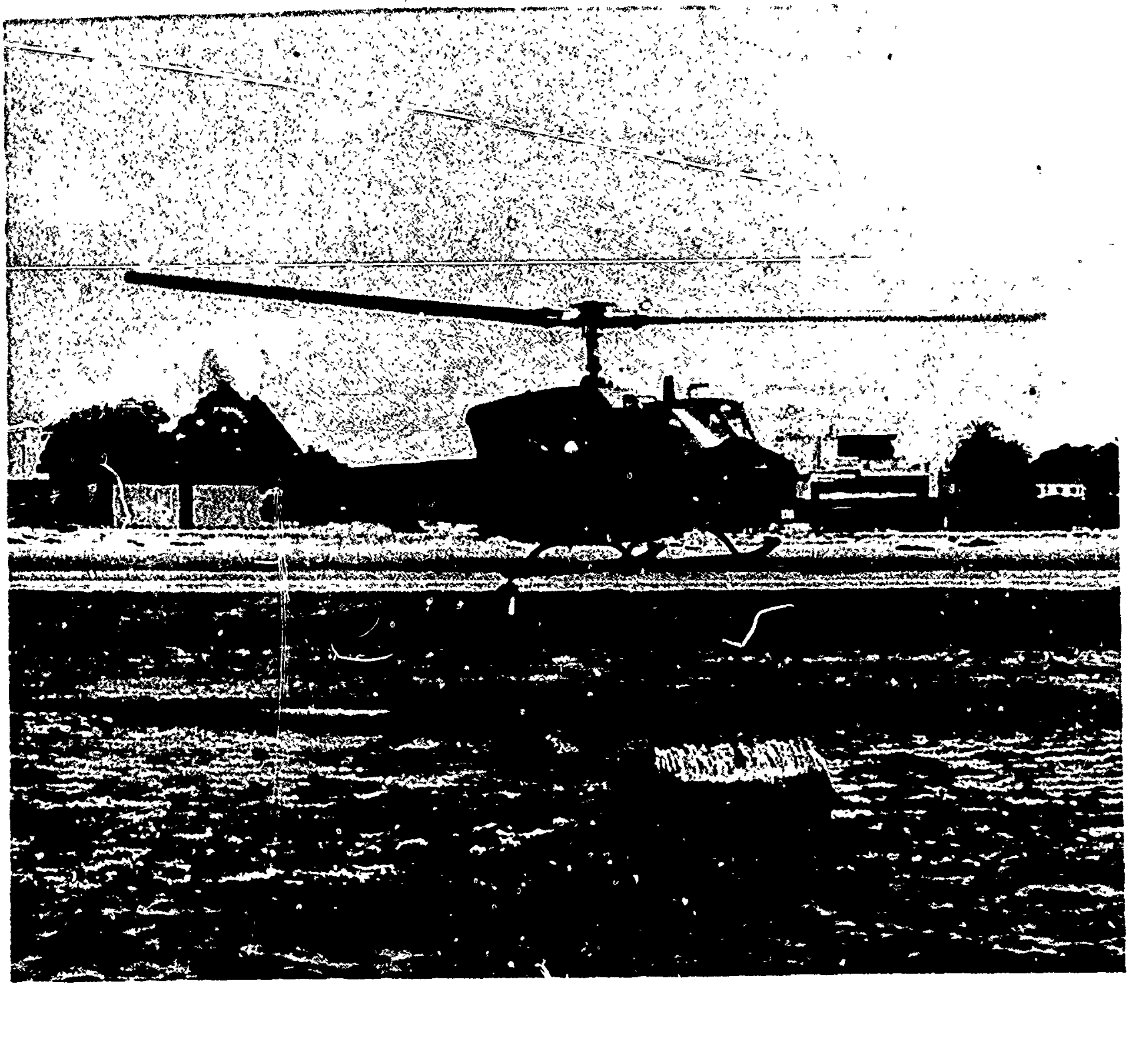
The internal rescue hoist qualitatively evaluated during the test program was updated by ECP 652ERI. The hoist was not available during the first week of the program. The rescue hoist was cycled during sustained hover operations from 3 through 8 May.

The rescue hoist was loaded with 150 pounds of dead weight and cycled at approximately three-minute intervals. The dead weight and about five feet of cable were allowed to run into the water before the reel-in was begun. The cable drum and mechanisms were allowed to get as wet as possible under these test conditions.

The rescue hoist was cycled a total of 55 cycles from 5 feet, 43 cycles from 10 feet, 38 cycles from 15 feet, 1 cycle from 40 feet and 1 cycle from 200 feet.

The hoist motor became progressively warmer as the height of the cycle increased. Overheating was not a problem, however, and even after

the 200-foot cycle, the hoist motor casing could be held with the bare hand. No difficulties were encountered with the rescue hoist, except for a minor corrosion problem which is noted in appendix III.



# CONCLUSIONS AND RECOMMENDATIONS

The UH-1N was evaluated during sustained hovering in salt water spray. Engine power loss resulting from salt spray ingestion did not occur rapidly enough to restrict the operation of the UH-1N in the salt spray environment. The T400 engine lost power at the rate of 1/2 to 1 percent torque per hour of hovering when the UH-1N was hovered at altitudes low enough and in wind conditions high enough to cause salt spray to be ingested by the engine power sections. Topping power checks proved to be the best inflight indicator of engine power deterioration, but these procedures are not available to all operational pilots. Although time consuming, the presently prescribed performance recovery wash was adequate to restore lost engine power. Operation of the UH-1N in salt spray caused significant aircraft corrosion problems which required daily corrosion control measures. Long term corrosion problems may represent a more serious problem than engine power degradation resulting from salt spray ingestion. The improved rescue hoist (ECP 652ERI) operated satisfactorily during these evaluations.

Maintaining a hover in ground effect required continual power adjustments and directional pedal inputs which produced continually fluctuating engine performance instrument indications. This, combined with changes in torque requirements due to rotor blade salt incrustation, made impossible the detection of small changes in instrument values caused by salt spray ingestion. Observation of the cockpit performance instruments while maintaining a hover in salt spray was therefore not sufficient by itself to indicate engine power deterioration resulting from ingestion of salt spray into the engines.

Power assurance checks were not sensitive enough to detect small power losses and did not correlate with topping power checks. Successive inflight power assurance checks were therefore not adequate indicators of engine power degradation resulting from the ingestion of salt spray.

1. Power assurance checks should not be used as a basis for engine rejection due to power deterioration below minimum acceptable values (page 7).

The present wording in the Functional Check Flight Procedures is inadequate with regard to topping power checks in that it does not make a distinction between the stabilization periods required when topping on $N_g$ and when topping on ITT. Topping on ITT took 4 to 5 minutes compared to the minimum of 30 seconds required when topping on $N_g$.

2. The Functional Check Flight Procedures should be amended to include instructions to hold topping power four to five minutes if necessary to obtain stabilized engine performance when topped on ITT (page 8).

The topping power check was the best method evaluated of determining engine power degradation. Topping power check procedures were not included in the Flight Manual. They appear only in the Functional Check Flight Procedures and are therefore not available to all operational pilots.

3. To make it possible for operational pilots to use the topping power check to determine engine power degradation, the topping power check procedures should also be included in the Flight Manual (page 8).

Topping power checks must be performed carefully to yield correct instrument values. When performed on an ITT-topped engine, they were very time consuming. Therefore, topping power checks may not be the best possible inflight indicator of engine performance.

4. An easier and more efficient method of determining engine performance during flight should be developed for the T400 engine (page 9).

Engine power loss as a result of sustained hovering in salt spray occurred at the rate of 1/2 to 1 percent torque per hour of hovering.

5. Prior to initiation of hovering in salt spray, a topping power check should be performed to determine initial acceptability. If an engine demonstrates two percent excess power or more, its condition need not be checked during the salt water mission. If the engine shows less than two percent excess power, a topping power check should be performed after each 30 minutes of hovering in the salt spray (page 10).

The presently authorized performance recovery wash was adequate to remove salt build-up from the T400 compressor. A full performance recovery wash would require 25 minutes if both engines were washed simultaneously and 45 to 50 minutes if the engines were washed consecutively. This would be very time consuming for an operational unit which would require one and possibly two performance washes per day per aircraft.

6. Although the presently specified performance recovery wash was satisfactory for cleaning the engines, shorter wash cycles which might achieve the same results while requiring less ground running should be investigated (page 18).

Main and tail rotor blade salt incrustation was experienced during this evaluation. No attempt was made to determine the effects of these conditions on the performance and flying qualities of the UH-1N; however, an out-of-track main rotor was experienced as a result. In addition, tail rotor "buzz" and airframe vibration were noted.

7. The Flight Manual should be amended to include the following statement (page 21):

> Sustained hovering in salt spray will cause salt incrustation on the main rotor and tail rotor blades. Such salt incrustation may cause abnormal aircraft vibrations which may be felt as a one per revolution "beat" from an out-of-track main rotor blade, tail rotor pedal "buzz" or higher frequency airframe vibrations transmitted from the tail rotor.

Spray impingement on the windscreen was the best indicator of salt spray ingestion by the engine intakes. With prevailing winds of five knots or less, the UH-1N could be hovered down to a five-foot hover height without ingestion of salt spray and accompanying power loss. With pre-

vailing winds of 6 to 16 knots and aircraft gross weight at 9,000 pounds or less, salt spray ingestion and accompanying power loss occurred at hover heights up to 25 to 30 feet. With prevailing winds of 6 to 16 knots and aircraft gross weight at 9,000 to 10,000 pounds, salt spray ingestion and the accompanying power loss occurred at hover heights up to 40 to 45 feet. There was no advantage in hovering crosswind or downwind for overwater hover operations due to the increased pilot workload.

8. All overwater hover operations should be conducted into the wind when there is sufficient wind to cause spray impingement on the helicopter windshield (winds of 6 knots or greater) (page 26).

In wind conditions of 6 knots or greater, the pilot workload to maintain a hover at 10 feet or less proved very high, and prolonged hovering at these heights was very tiring. Fifteen feet was a good compromise between a relatively stable hover height and a hover height from which adequate visual reference could be maintained.

9. For prolonged hover operations over water, hover altitudes below 15 feet should not be used unless required by operational necessity (page 26).

Hovering in salt spray will cause extensive aircraft corrosion unless adequate corrosion control is practiced on a daily basis. This corrosion may be obvious or insidious and may prove to be a more serious problem than engine power degradation resulting from sustained hovering in salt spray.

10. Hovering in salt spray should be kept to the minimum time required to accomplish an operational mission, and the hover altitude should be as high as is practical for that mission (page 28).

The pilot's jettisonable doors were most quickly and cleanly separated by "kicking sharply" on the forward bottom corner of the door instead of using a "manual push" as presently stated in the Flight Manual.

11. The Flight Manual should be amended to include the following (page 29):

NOTE

> A sharp kick against the bottom forward corner of the crew doors is required to jettison them after the jettison handle has been pulled.

12. Pilots regularly operating the UH-1N over water should be required to periodically practice jettisoning both the left and right pilot's doors (page 29).

# APPENDIX I

# INSTRUMENTATION LIST

| Photopanel | Range |
|---|---|
| Main rotor rpm | 0 - 100 |
| Airspeed | 0 - 150 (kt) |
| Pressure altitude | 0 - 50,000 ft |
| Free air temperature | ±60 deg C |
| Rate of climb | ±[illegible],000 fpm |
| Left engine rpm | 0 - 100 pct |
| Right engine rpm | 0 - 100 pct |
| Left engine ITT | 0 - 1,200 deg C |
| Right engine ITT | 0 - 1,200 deg C |
| Left engine torque | 0 - 100 pct |
| Right engine torque | 0 - 100 pct |
| Left engine power turbine rpm | 0 - 100 pct |
| Right engine power turbine rpm | 0 - 100 pct |
| Left engine fuel flow | 0 - 1,200 pph |
| Right engine fuel flow | 0 - 1,200 pph |
| Fuel quantity remaining | 0 - 1,575 lb |

# APPENDIX II

# RIGHT ENGINE PERFORMANCE DATA

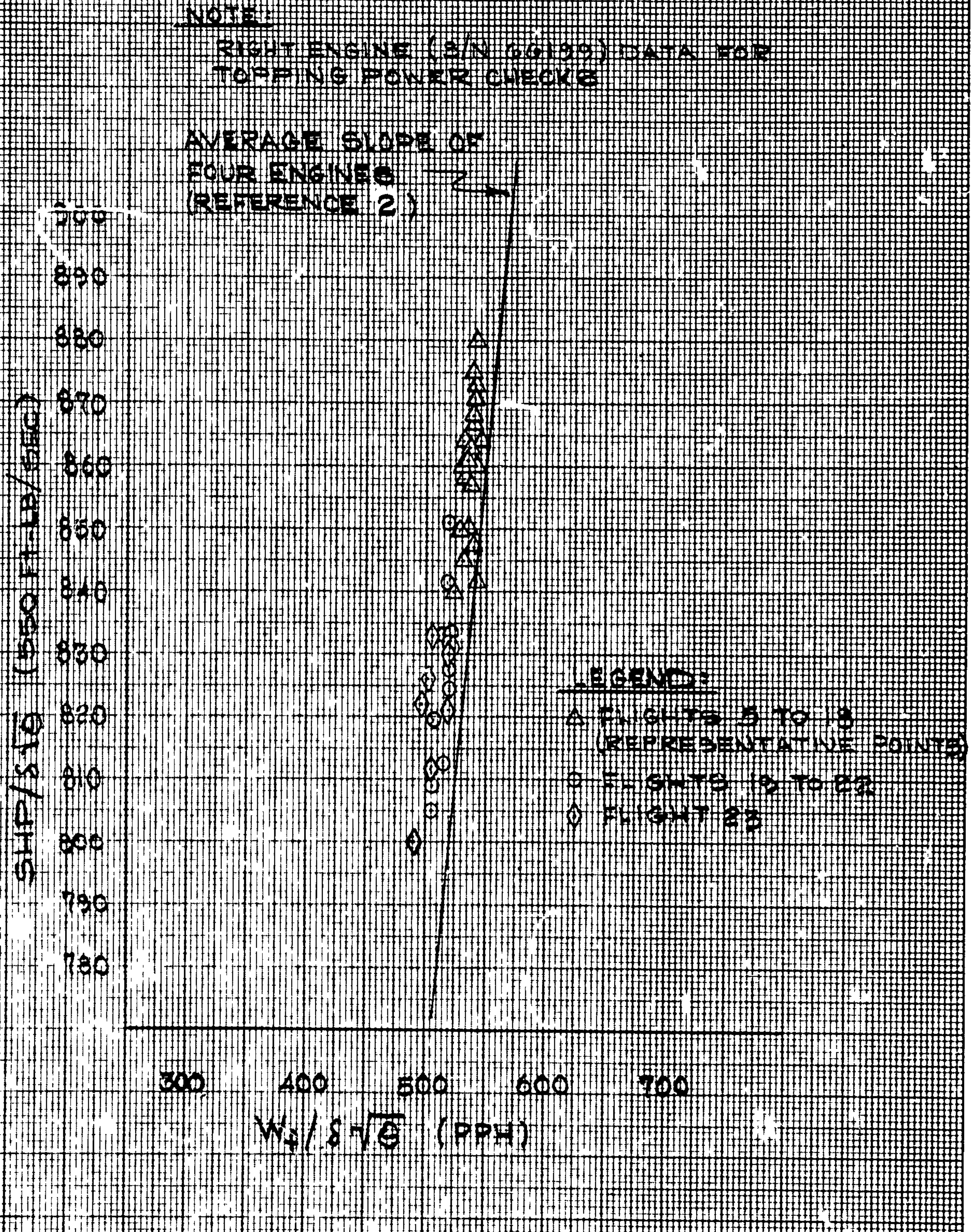



FIGURE 12: REFERRED SHAFT HORSEPOWER VS REFERRED FUEL FLOW

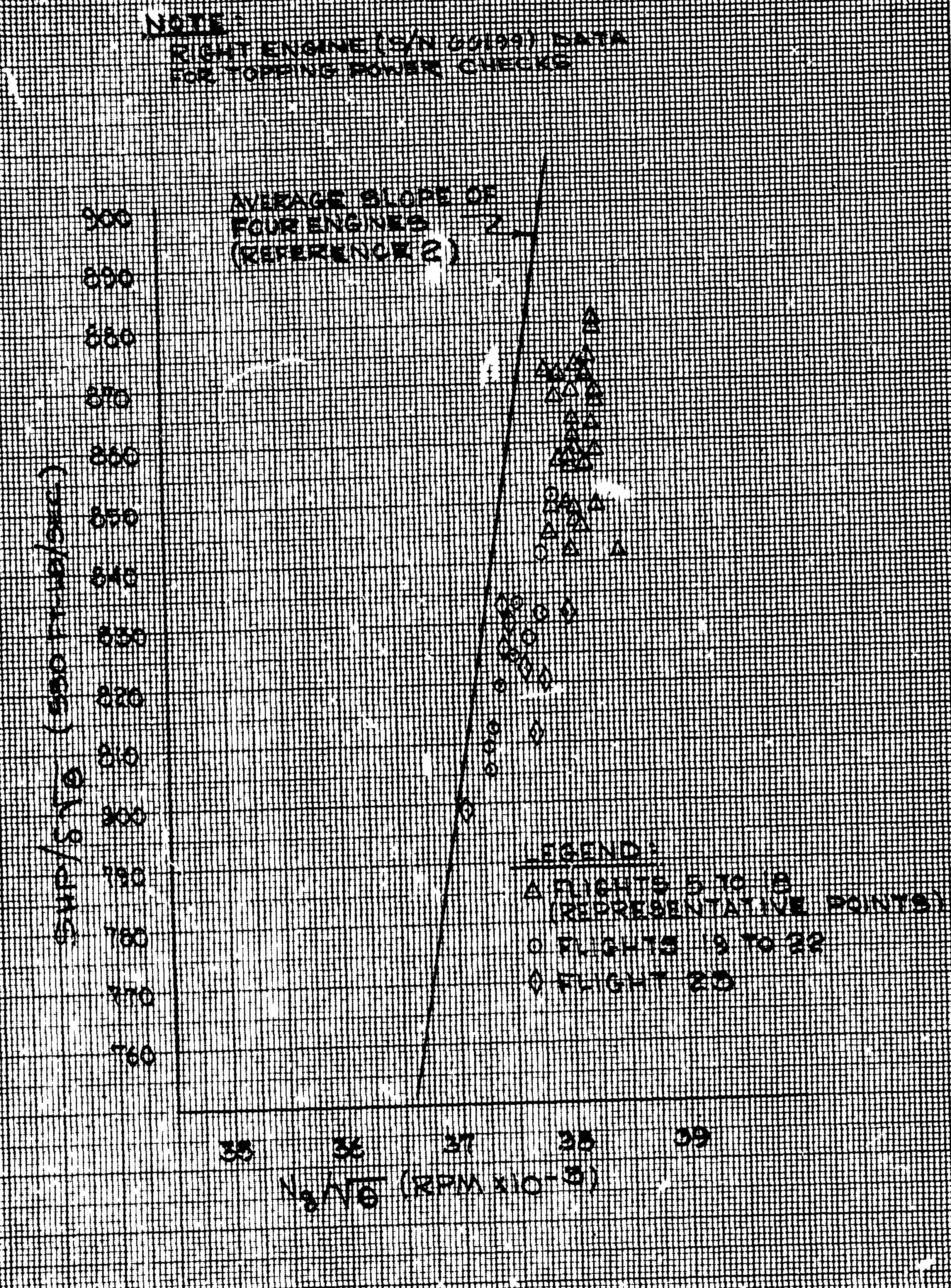



FIGURE 13: REFERRED SHAFT HORSEPOWER VS REFERRED GAS GENERATOR SPEED

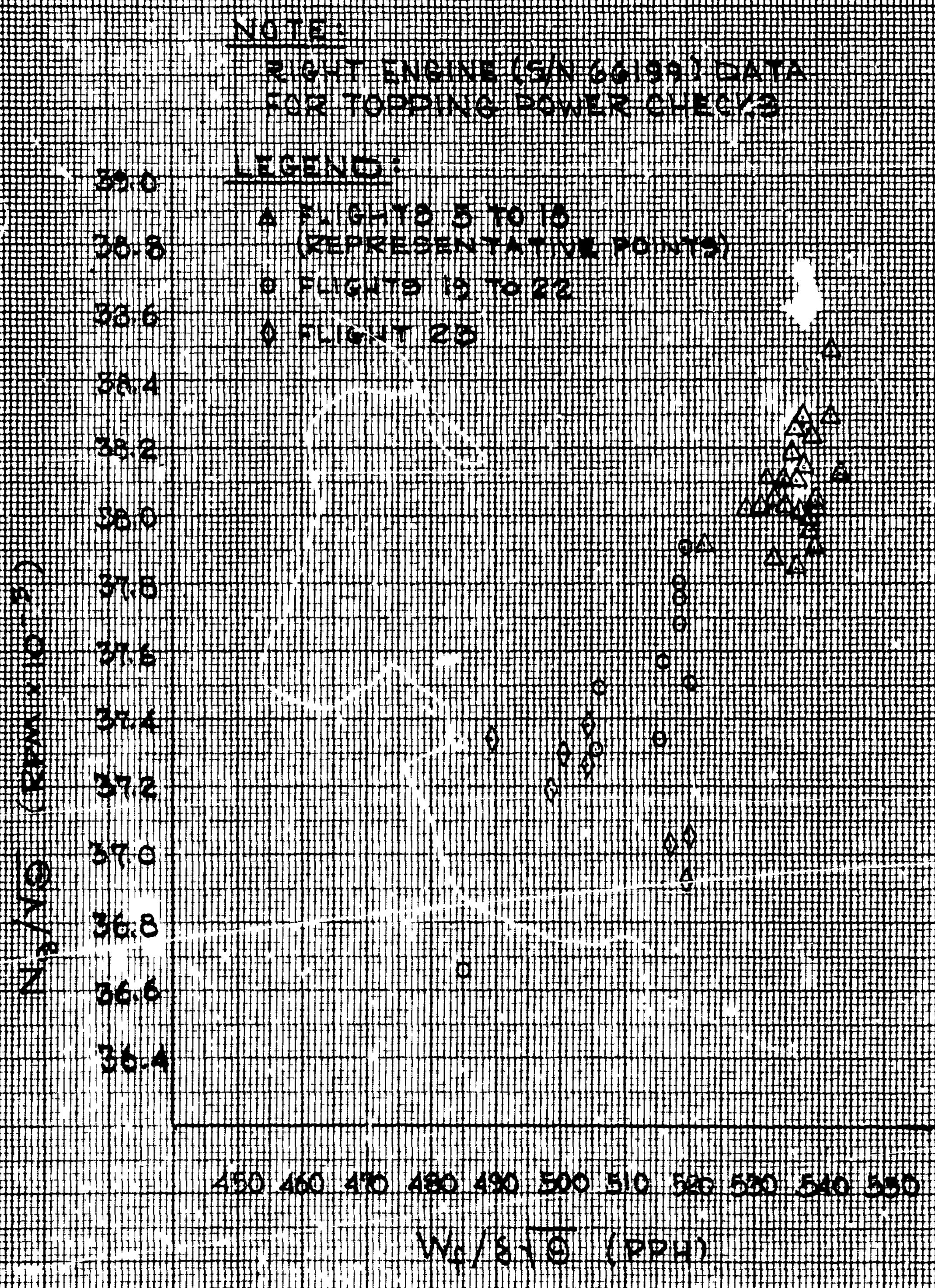



FIGURE 14: REFERRED GAS GENERATOR SPEED VS REFERRED FUEL FLOW

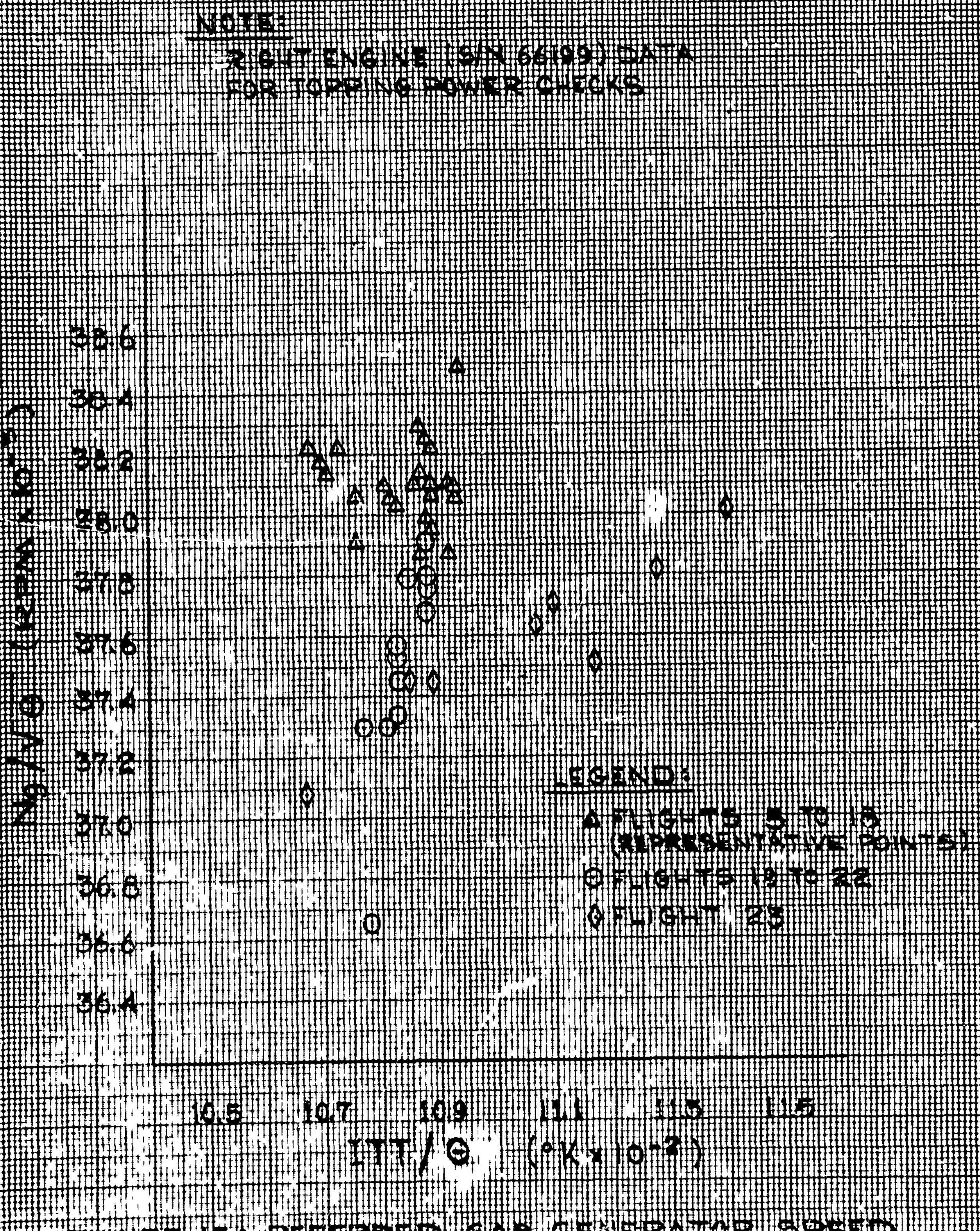



FIGURE 15: REFERRED GAS GENERATOR SPEED VS REFERRED INTER-TURBINE TEMPERATURE

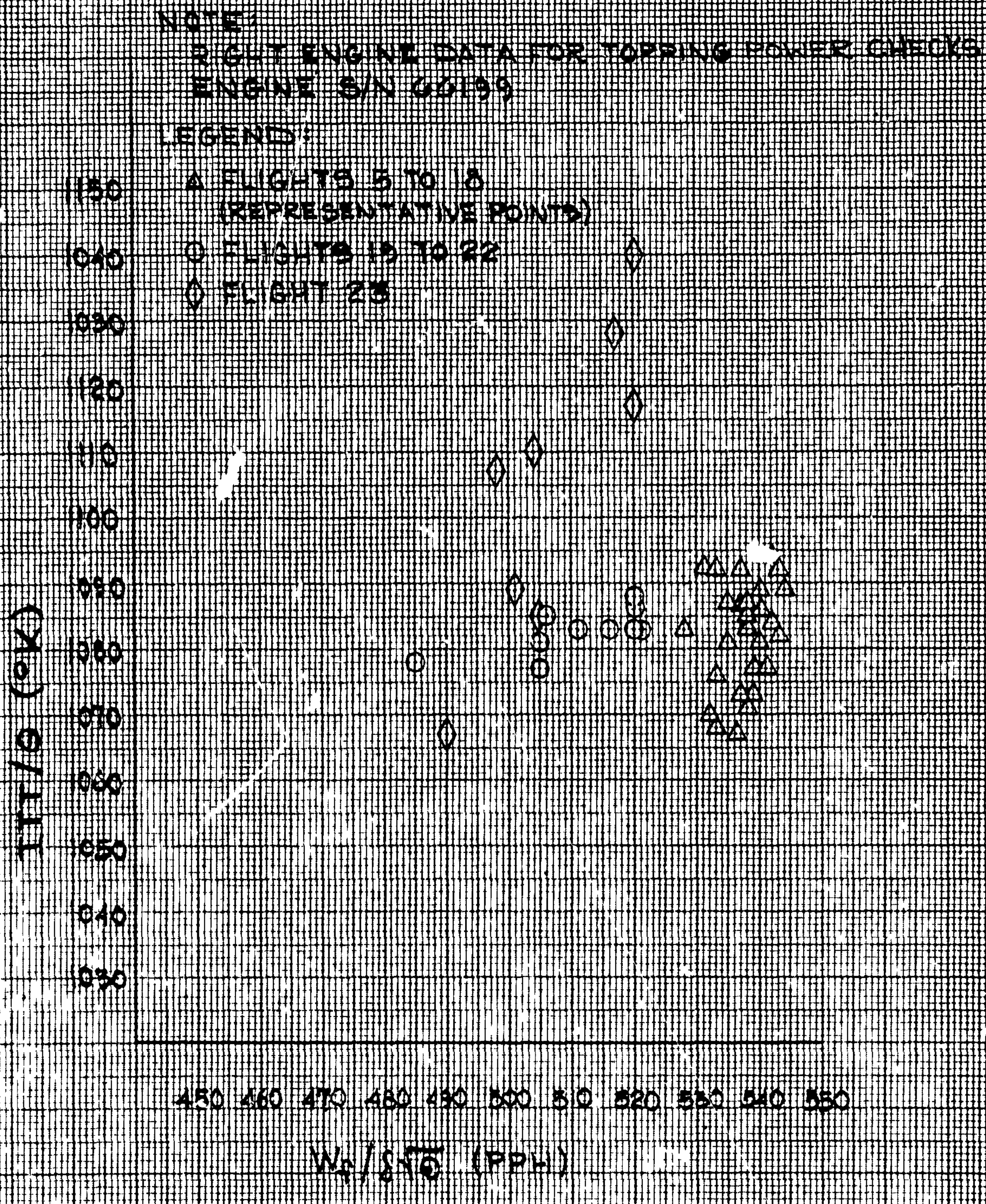



FIGURE 16: REFERRED INTER-TURBINE TEMPERATURE VS REFERRED FUEL FLOW

# APPENDIX III
# CORROSION CONTROL SUMMARY

### FORWARD FUSELAGE

1. Discrepancy: Those screw heads in the roof with inadequate paint protection corroded.

   Corrective Action: Cleaned and treated with zinc chromate.

2. Discrepancy: Battery compartment weather stripping loose from salt spray and washing.

   Corrective Action: Weather stripping reglued.

3. Discrepancy: Front cabin door swing stops were corroded where paint was worn.

   Corrective Action: Treated with Grade 4 preservative.

### TRANSMISSION AND MAST

4. Discrepancy: Spline shaft at damper mount points corroded.

   Corrective Action: Cleaned and greased thoroughly.

### MAIN ROTOR AND CONTROLS

5. Discrepancy: Rotor blade retaining bolts and nuts excessively corroded.

   Corrective Action: Cleaned and treated with Grade 4 preservative.

6. Discrepancy: Nut faces on pitch links corroded.

   Corrective Action: Cleaned and treated with Grade 4 preservative.

### TRANSMISSION AND ENGINE COWLING

7. Discrepancy: All rivets, screws, and bolts which were not previously protected corroded.

   Corrective Action: Cleaned and treated with zinc chromate and Grade 4 preservative.

### POWER PACKAGE

8. Discrepancy: Left engine exhaust duct to gas generator case retaining bolts and nuts corroded excessively.

   Corrective Action: Not treated due to heat consideration.

9. Discrepancy: Compressor discharge bleed air tubing and mount fittings corroded.

Corrective Action: Not treated due to heat consideration.

10. Discrepancy: Air management guide duct bolts at .ir particle separator housing corroded.

Corrective Action: Not treated due to heat consideration.

11. Discrepancy: Salt residue noted in ejector tubes and interior of blast duct.

Corrective Action: Insure EAPS doors are opened during aircraft washing.

12. Discrepancy: Igniter plug fittings at combustion chamber liner corroded.

Corrective Action: Cleaned.

13. Discrepancy: Scavenge oil fitting at 7 o'clock position corroded (both engines).

Corrective Action: None.

14. Discrepancy: Fuel pressure compensator corroded excessively (both engines).

Corrective Action: Coated with No. 40 lubricant.

15. Discrepancy: Blast tube retaining bolts and nuts corroded.

Corrective Action: None.

16. Discrepancy: Exterior fittings on fuel controls corroded (both engines, more severely on the left engine).

Corrective Action: Treated with silicone spray lubricant.

## MAIN DRIVE SHAFT

17. Discrepancy: Salt residue noted on drive shaft.

Corrective Action: Improved aircraft daily wash.

## TAIL ROTOR AND GEARBOX

18. Discrepancy: All bearings in hub corroded.

Corrective Action: Treated with silicone spray lubricant.

## TAIL BOOM

19. Discrepancy: All exterior unprotected bolts corroded.

Corrective Action: Coated with Grade 4 preservative.

## LANDING GEAR (Skids)

20. Discrepancy: Rubber cushions separated due to exposure to salt water environment.

Corrective Action: Removed and replaced.

**INTERNAL RESCUE HOIST**

21. Discrepancy: Hoist actuator arm and level wind worm screw on piston corroded.

Corrective Action: Treated with silicone spray lubricant.

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UNCLASSIFIED
Security Classification

# DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

| | |
|---|---|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Air Force Flight Test Center<br>Edwards AFB, California | 2a. REPORT SECURITY CLASSIFICATION<br>Unclassified<br>2b. GROUP<br>N/A |

3. REPORT TITLE

UH-1N Salt Water Spray Ingestion Tests (Category II Follow-On Test Program)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Final

5. AUTHOR(S) (First name, middle initial, last name)
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Clark F. Lovrien, Major USAF

| 6. REPORT DATE | 7a. TOTAL NO. OF PAGES | 7b. NO. OF REFS |
|---|---|---|
| October 1972 | 43 | 4 |

| | |
|---|---|
| 8a. CONTRACT OR GRANT NO.<br>b. PROJECT NO.<br>c. Project Directive 72-116<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>FTC-TR-72-39<br>9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)<br>N/A |

10 DISTRIBUTION STATEMENT Distribution limited to U.S. Government agencies only (Test and Evaluation), August 1972. Other requests for this document must be referred to ASD (SDQH), Wright-Patterson AFB, Ohio 45433.

| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY |
|---|---|
| N/A | 6510 Test Wing<br>Edwards AFB, California |

13 ABSTRACT This report presents the results of the UH-1N salt water spray ingestion test program which was conducted to provide information to the Aerospace Rescue and Recovery Service. The UH-1N was found to lose power at the maximum rate of 1/2 to 1 percent torque per engine per hour of hovering in salt spray. The topping power check was found to be the best inflight indicator of engine power degradation. Topping power check procedures should be included in the Flight Manual to make them available to operational pilots for use in checking engine condition. The presently prescribed performance recovery wash, although too time consuming, was adequate to restore engine pcwer. Spray impingement on the helicopter windscreen was an adequate indication of salt spray ingestion by the engines. Salt spray ingestion occurred at hover heights of 45 feet or less when the aircraft was hovered at gross weights between 9,000 and 10,000 pounds with prevailing winds of 6 to 16 knots. At gross weights of 9,000 pounds or less and wind conditions of 6 to 16 knots, salt spray ingestion occurred at hover heights of 30 feet or less. No ingestion occurred at any hover height down to five feet when wind conditions were five knots or less. Sustained hovering in salt spray caused significant aircraft corrosion problems which required daily corrosion control efforts. Long term corrosion effects may represent a more serious problem than engine power degradation.

DD FORM 1 NOV 65 1473

UNCLASSIFIED
Security Classification

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Security Classification

| 14 KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| UH-1N helicopter | | | | | | |
| salt spray ingestion | | | | | | |
| corrosion | | | | | | |
| corrosion control | | | | | | |
| power degradation | | | | | | |
| rescue hoist | | | | | | |

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